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TRANSIT COOPERATIVE RESEARCH PROGRAM
AND
NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

TCRP REPORT 112/NCHRP REPORT 562

Improving Pedestrian Safety at Unsignalized Crossings

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Subject Areas
Operations and Safety • Public Transit

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TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2006
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The nation's growth and the need to meet mobility, environmental, and energy objectives place demands on public transit systems. Current systems, some of which are old and in need of upgrading, must expand service area, increase service frequency, and improve efficiency to serve these demands. Research is necessary to solve operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the transit industry. The Transit Cooperative Research Program (TCRP) serves as one of the principal means by which the transit industry can develop innovative near-term solutions to meet demands placed on it.

The need for TCRP was originally identified in *TRB Special Report 213—Research for Public Transit: New Directions,* published in 1987 and based on a study sponsored by the Urban Mass Transportation Administration—now the Federal Transit Administration (FTA). A report by the American Public Transportation Association (APTA), Transportation 2000, also recognized the need for local, problem-solving research. TCRP, modeled after the longstanding and successful National Cooperative Highway Research Program, undertakes research and other technical activities in response to the needs of transit service providers. The scope of TCRP includes a variety of transit research fields including planning, service configuration, equipment, facilities, operations, human resources, maintenance, policy, and administrative practices.

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Research problem statements for TCRP are solicited periodically but may be submitted to TRB by anyone at any time. It is the responsibility of the TOPS Committee to formulate the research program by identifying the highest priority projects. As part of the evaluation, the TOPS Committee defines funding levels and expected products.

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Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Academies was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NCHRP REPORT 562

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Kay Fitzpatrick of TTI was the principal investigator. Primary authors of this report are Kay Fitzpatrick (research engineer), Shawn Turner (associate research engineer), and Marcus Brewer (assistant research engineer), all of TTI. Assisting the primary authors were Paul Carlson (associate research engineer, TTI), Nazir Lalani (principal associate of Traffex Engineers, Inc.), Brooke Ullman (associate transportation researcher, TTI), Nada Trout (assistant research scientist, TTI), Eun Sug Park (assistant research scientist, TTI), Dominique Lord (assistant professor, Texas A&M University), and Jeff Whitacre (graduate research assistant, TTI). The work was performed under the general supervision of Dr. Fitzpatrick.

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FOREWORD

By Dianne S. Schwager
Staff Officer
Transportation Research Board

TCRP Report 112/NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings will be of interest to state, county, and city traffic engineers; transit agencies; roadway designers; and urban planners, as well as consultants for these groups and agencies. This material provides considerable information and useful guidance for improving pedestrian safety at unsignalized crossings. The report presents the edited final report and Appendix A. *TCRP Web-Only Document 30/NCHRP Web-Only Document 91,* available on the CRP website, contains appendixes B through O of the contractor's final report.

A recent research project jointly sponsored by the TCRP and the NCHRP had two main objectives:

- Recommend selected engineering treatments to improve safety for pedestrians crossing high-volume, high-speed roadways at unsignalized intersections, in particular on roads served by public transportation; and
- Recommend modifications to the *Manual on Uniform Traffic Control Devices* (MUTCD) pedestrian traffic signal warrant.

The research team developed guidelines that can be used to select pedestrian crossing treatments for unsignalized intersections and midblock locations (*Guidelines for Pedestrian Crossing Treatments*). Quantitative procedures in the guidelines use key input variables (such as pedestrian volume, street crossing width, and traffic volume) to recommend one of four possible crossing treatment categories. The research team developed and presented recommendations to revise the MUTCD pedestrian warrant for traffic control signals to the National Committee on Uniform Traffic Control Devices.

In accomplishing the two main study objectives, the research team also developed useful supporting information such as findings from the field studies on walking speed and motorist compliance. Pedestrian walking speed recommendations were 3.5 ft/s (1.1 m/s) for the general population and 3.0 ft/s (0.9 m/s) for the older or less able population. Motorist compliance (with yielding or stopping where required) was the primary measure of effectiveness for engineering treatments at unsignalized roadway crossings. The study found that the type of crossing treatment affects motorist compliance; other factors influencing the treatment effectiveness were the number of lanes being crossed and posted speed limit.

TCRP Report 112/NCHRP Report 562 and its appendixes provide useful information and tools for those interested in improving pedestrian safety at unsignalized crossings.

CONTENTS

SUMMARY

Improving Pedestrian Safety at Unsignalized Crossings

There has been an increased emphasis on improving pedestrian safety. The desire to improve pedestrian safety extends to areas typically seen as being non-pedestrian-friendly, such as the higher speeds and wider roadways. With traffic conditions changing as traffic volumes and congestion increase, pedestrians' ability to safely cross many roadways is affected. Recent developments in geometric design features, traffic control devices, and technologies may improve pedestrian safety and access by addressing specific problems associated with roadway crossings. Although numerous treatments exist at unsignalized crossings, there is growing concern about their effectiveness. Thus, there is a need to identify and study selected treatments to determine their effectiveness. A recent research project jointly sponsored by TCRP and NCHRP was initiated to address this particular need. The research was conducted by the Texas Transportation Institute (TTI).

The study had two main objectives: (1) to recommend selected engineering treatments to improve safety for pedestrians crossing high-volume, high-speed roadways at unsignalized intersections, in particular those served by public transportation; and (2) to recommend modifications to the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) pedestrian traffic signal warrant.

The research team developed guidelines for use in selecting pedestrian crossing treatments for unsignalized intersections and midblock locations (*Guidelines for Pedestrian Crossing Treatments*, included in this report as Appendix A). Quantitative procedures in the guidelines use key input variables (such as pedestrian volume, street crossing width, and traffic volume) to recommend one of four possible crossing treatment categories: marked crosswalk; enhanced, high-visibility, or "active when present" traffic control device; red signal or beacon device; and conventional traffic control signal. The guidelines include supporting information for these treatment categories as well as examples and pictures of traffic control devices in each treatment category. The audience for these guidelines includes state, county, and city traffic engineers; transit agencies; roadway designers; and urban planners; as well as consultants for these groups and agencies.

The research team developed and presented recommendations to the National Committee on Uniform Traffic Control Devices to revise the MUTCD pedestrian warrant for traffic control signals. The proposed revisions were derived from other vehicle-based traffic signal warrants and supplemented with data gathered during the study. The basis for the proposed pedestrian warrant revisions is that the number of pedestrians waiting to cross a street should be no greater than the number of vehicles waiting to cross or enter a street. Once this basis was accepted, then the existing vehicle-based warrants were used to derive comparable warrants for crossing pedestrians. In addition to traffic signal warrant revisions, the research team identified two other MUTCD sections that could be revised. The first revision is a minor addition that suggests the use of median refuge islands or curb extensions as alternatives to traffic control signals. The second revision is the inclusion of a new type of highway traffic signal, Pedestrian Traffic Control Signals, in the MUTCD.

In accomplishing the two main study objectives, the research team also developed useful supporting information on various aspects of pedestrian safety at unsignalized roadway crossings. Two examples are the findings from the field studies on walking speed and motorist compliance. In total, 42 study sites were selected in seven different states for the field studies. The study sites were chosen so as to distribute the different types of crossing treatments in certain regions, so that data for a particular treatment were not collected from a single city. The field studies included nine different types of pedestrian crossing treatments.

A total of 3,155 pedestrians were recorded during the field study. Of that value, 81 percent (2,552 pedestrians) were observed as "walking." The remaining 19 percent of the pedestrians (603) were observed to be running, both walking and running during the crossing, or using some form of assistance (such as skates or bicycles). Comparing the findings from the TCRP/NCHRP field study with previous work resulted in the following walking speed recommendations: 3.5 ft/s (1.1 m/s) for the general population and 3.0 ft/s (0.9 m/s) for the older or less able population.

The research team chose motorist compliance (that is, yielding or stopping where required) as the primary measure of effectiveness for engineering treatments at unsignalized roadway crossings. In addition to collecting motorist yielding behavior for general population pedestrians, the data collection personnel also staged street crossings to ensure consistency among all sites as well as adequate sample sizes. The study found that the crossing treatment affects motorist compliance. Those treatments that show a red signal indication to the motorist have a statistically significant different compliance rate from devices that do not show a red indication. These red signal or beacon devices had compliance rates greater than 95 percent and include midblock signals, half signals, and high-intensity activated crosswalk (HAWK) signal beacons. Nearly all the red signal or beacon treatments evaluated were used on busy, high-speed arterial streets. Pedestrian crossing flags and in-street crossing signs also were effective in prompting motorist yielding, achieving 65 and 87 percent compliance, respectively. However, most of these crossing treatments were installed on lower-speed and lower-volume, two-lane roadways. The measured motorist compliance for many crossing treatments varied considerably among sites. Number of lanes being crossed and posted speed limit were other factors in addition to type of treatment influencing the effectiveness of the crossing treatments.

CHAPTER 1

Introduction

Background

With the movement toward livable communities, where walking and using transit are attractive transportation options, there is an increasing desire to improve pedestrian safety. This desire extends to areas typically seen as being non-pedestrian-friendly, such as the higher speed and wider roadways, especially when these roadways serve as transit routes. With traffic conditions changing as vehicle volumes and congestion increase, these changes have affected pedestrians' ability to cross many roadways safely.

Recent developments in geometric design features, traffic control devices, and technologies may improve pedestrian safety and access by addressing specific problems associated with roadway crossings. Although numerous treatments exist at unsignalized crossings, there is growing concern about their effectiveness. Thus, there is a need to identify and study selected treatments to determine their effectiveness. A recent research project jointly sponsored by TCRP and NCHRP was initiated to address this particular need. The research was conducted by the Texas Transportation Institute (TTI).

One objective of the research was to recommend selected engineering treatments to improve safety for pedestrians crossing at unsignalized locations, particularly locations served by public transportation. Another objective was to examine the *Manual on Uniform Traffic Control Devices on Streets and Highways* (MUTCD) (*1*) pedestrian signal warrant, because there is concern that the existing traffic signal pedestrian warrant may need to be modified. For example, state and local transportation agencies often have difficulty justifying the installation of traffic signals at pedestrian crossing locations. Many of these locations are experiencing traffic volume increases, along with reductions in vehicle gaps that provide opportunities for the safe crossing of pedestrians. Transit stops may exist on both sides of these roadways, creating challenging pedestrian crossing conditions. In these (often suburban) locations, meeting the pedestrian volumes specified in the warrant is rarely possible.

So as to provide more than just a list of possible treatments, the research team developed quantitative guidelines to help engineers and transit agencies decide which treatments are recommended for different street environments and traffic conditions. In accomplishing this, the team evaluated various pedestrian crossing treatments and documented the results. The guidelines are included in Appendix A of this report.

Objectives

The objectives of this research were to

- Recommend selected engineering treatments to improve safety for pedestrians crossing high-volume and high-speed roadways at unsignalized locations, in particular those locations served by public transportation; and
- Recommend modifications to the MUTCD pedestrian traffic signal warrant.

Approach

The research had two phases. Phase I focused on reviewing the literature, conducting surveys, and evaluating the state of the practice, and concluded with the development of a study approach for Phase II to accomplish the research project's two objectives.

Phase I activities included the following:

- Review of current practice for crossing treatments through a search of the literature and interviews with providers,
- Conduct of surveys of pedestrians to establish their experiences and needs at unsignalized pedestrian crossing locations,
- Assessment of pedestrian crossing designs,
- Evaluation of the adequacy of the pedestrian signal warrant and development of preliminary recommendations for modifying the current warrant, and
- Preparation of the evaluation research plan.

The focus of Phase II was to collect data and conduct evaluations to permit development of guidelines on selecting pedestrian treatments. These guidelines were to include the criteria for warranting a traffic signal. The major Phase II activities were

- Conduct of field studies that collected data on many pedestrian and motorist behaviors with an emphasis on walking speed, motorist compliance, and pedestrian-vehicle conflicts;
- Exploration of how different criteria (e.g., number of pedestrians or vehicles, delay, and major-road speed) could be used in selecting pedestrian crossing treatment;
- Development and testing of guidelines;
- Production of recommendations on changes to the MUTCD; and
- Documentation of procedures and findings.

Organization of this Report

For this report, details on the research methodology and findings are in the appendixes; the chapters summarize the key elements of the research. Chapter 1 contains the background, objectives, and overview of the research approach along with this section on the organization of the report. Chapter 2 presents information on pedestrian characteristics. Chapter 3 reviews pedestrian crossing treatments, while Chapter 4 reviews the MUTCD pedestrian signal warrant. Findings from surveys of providers and pedestrians are discussed in Chapter 5. Chapters 6 and 7 present the methodology for the field studies and the field studies findings, respectively. Chapter 8 presents the conclusions and recommendations from the research.

Table 1 summarizes the material contained in each chapter and the appendixes that support the topic. The printed report contains the chapters and Appendix A. The other appendixes are published as a web-only document available at the following address:

http://www4.trb.org/trb/onlinepubs.nsf/web/tcrp_web_documents.

The accomplishment of the objectives are discussed in Appendixes A and B.

Appendix A contains the recommended *Guidelines for Pedestrian Crossing Treatments.* These guidelines are intended to provide general recommendations on pedestrian crossing treatments to consider at uncontrolled locations. The guidelines note that, in all cases, engineering judgment should be used in selecting a specific treatment for installation. The guidelines build on the recommendations of several studies and focus on unsignalized locations—they do not apply to school crossings. Considerations (in addition to the procedure

Table 1. Overview of report.

Chapter	Topic ■ **Supporting Appendices**
1	Introduction
2	Pedestrian Characteristics
3	Pedestrian Crossing Treatments ■ Appendix C–Literature Review of Pedestrian Crossing Treatments at Uncontrolled Locations ■ Appendix D–Pedestrian Crossing Treatments ■ Appendix E–Summary of Pedestrian Crossing Treatment Evaluations ■ Appendix F–Pedestrian Crossing Installation Guidelines
4	Pedestrian Signal Warrants ■ Appendix G–International Signal Warranting Practices ■ Appendix H–Adequacy of Pedestrian Signal Warrant ■ Appendix I–Suggested Issues to Consider When Revising the Pedestrian Signal Warrant
5	Surveys ■ Appendix J–Survey of Providers ■ Appendix K–On-Street Pedestrian Surveys
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8	Conclusions and Recommendations ■ Appendix A–Guidelines for Pedestrian Crossing Treatments ■ Appendix B–Proposed Changes to MUTCD

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provided in these guidelines) should be used at locations where installing a pedestrian treatment could increase safety risks to pedestrians, such as where there is poor sight distance, complex geometrics, or proximity of traffic signals.

Appendix B contains the recommendations for changes to the MUTCD as presented to the National Committee on Uniform Traffic Control Devices (NCUTCD). The changes are shown as strikeouts and underlines within a reproduction of the relevant pages of the MUTCD. The recommendations are grouped into three proposals. The first proposal deals directly with the pedestrian signal warrant. The second proposal adds advice on using a refuge island as an alternative to traffic control signals. Adding a new device to the MUTCD, called a pedestrian traffic control signal, is the third proposal.

CHAPTER 2

Pedestrian Characteristics

Why People Walk

The decision to walk usually takes into account the distance of the trip, the perceived safety of the route, and the comfort and convenience of walking versus an alternative mode (*2*). Distance is the primary factor in the initial decision to walk. Most pedestrian trips (73 percent) are 0.5 mile (0.8 km) or less (*3, 4*) in length, with 1 mile (1.6 km) generally being the limit that most people are willing to travel on foot. Effects on the perceived and actual safety of pedestrians include sidewalks that are too narrow or adjacent to moving lanes of traffic along with pedestrian crossings that are intimidating because of confusing signal indications, excessive crossing distances, or fast-turning vehicles. The immediate physical environment also affects the comfort and convenience of walking. For example, shade trees or places to sit and rest may encourage pedestrian activity. The appearance of buildings, landscaping, and the street itself can contribute to a pleasant visual environment. A 1990 Harris Poll found that 59 percent of all respondents would be willing to walk more often if there were safe, designated paths or walkways (*5*).

The 1995 Nationwide Personal Transportation Survey found person-trips to be distributed as follows: 5.4 percent walking, 86 percent private vehicles, 1.8 percent transit, 1.7 percent school bus, and 4.9 percent other (*3*). The 1995 survey also determined trips by trip purposes (see Table 2).

The Washington State DOT's *Pedestrian Facilities Guidebook* (*4*) determined similar purposes for pedestrian trips:

- To and from work and school,
- Social visits and events,
- Appointments,
- Health and exercise,
- Errands and deliveries,
- Recreation,
- Extracurricular activities,
- Combined (recreational walking while shopping), and
- Multimodal trips (walking to a bus stop).

Psychology of Space

To attract pedestrians to a place, these key psychological principles should be considered (*6*):

- **Security**. Streets with cars moving too fast or making too much noise or streets with too many hidden pockets, too little activity, places that are dark, isolated, or broken up by "dead" corners, open parking lots, blank walls, or block-long voids tend to dissuade people from walking there.
- **Comfort**. Streets should have basic amenities such as enough sidewalk space, separation from the street, an edge or transition between uses of space, shade, and rich visual scenery to attract the pedestrian.
- **Convenience**. Streets must provide a blend of services and economic life for the pedestrian.
- **Efficiency and Affordability**. Streets that are overly expensive for the volume and categories of people that will use them cannot pay their way, but the quality of a street should not be compromised.
- **Welcoming Feeling**. People must feel welcomed by the place and inspired to return, a feeling imparted by the employees of an establishment, by the people that share that street, and by the physical presence of the street itself.

Why People Do Not Walk

According to Washington State's *Pedestrian Facilities Guidebook* (*4*), pedestrian trips account for 39 percent of all trips less than 1 mile, ranking second only to private motor vehicle trips. Despite this percentage, walking typically composes only 1 to 4 percent of all commuter trips in the United States overall (*4*). Common reasons for low levels of pedestrian travel include

- Poor facilities or lack of sidewalks or walkways,
- Failure to provide a contiguous system of pedestrian facilities,

Table 2. Purposes for pedestrian trips. (*3*)

Purpose	Percent Walking for That Purpose	Percent of all Modes Traveling for That Purpose
Personal/Family Business	43	46
Social/Recreational	34	25
School/Church/Civic	14	9
Earning a Living	7	20
Other	2	0

- Concerns for personal safety,
- Failure to provide facilities to and from popular origins and destinations,
- Inclement weather,
- Poor lighting, and
- Lack of facilities separated from the roadway.

Pedestrian Settings

Urban Areas

Americans tend to walk more in urban cities with large populations occupying a small area, such as New York City, a city in which 70 percent of the population does not even own a car. Heavy traffic flow on roadways and limited or expensive parking facilities in these towns make walking seem the easier, faster, and cheaper choice. In addition, many large cities with higher pedestrian populations (such as Boston; Washington, D.C.; Chicago; and San Francisco) also offer access to efficient public transportation systems such as subways that attract pedestrian users. Other cities (such as Portland, Oregon; Seattle, Washington; and Boulder, Colorado) have increased pedestrian populations because of rigorous efforts by lawmakers and police officials to make and enforce laws to encourage and protect pedestrian activity. Following are further explanations for why urban areas have high pedestrian use (*4*):

- Traffic congestion is high.
- Origin and destination points are more numerous and denser in concentration.
- Shopping and services are more accessible to pedestrians.
- Average trip distances are shorter.
- Parking is too costly or unavailable.
- Transit service is more readily available.
- More pedestrian facilities are available.

Suburban and Rural Areas

Pedestrian travel is higher in urban areas, but pedestrians can also be found in suburban and rural areas. Suburban and rural pedestrian trips are often associated with walking to schools, school bus stops, or transit bus stops or for recreational and leisure purposes. Fewer people walk to run errands and shop or to reach community services (*4*).

Walking Speed

Pedestrians have a wide range of needs and abilities. The MUTCD (*1*) includes a speed of 4.0 ft/s (1.2 m/s) for calculating pedestrian clearance intervals for traffic signals. The MUTCD also includes a comment that, where pedestrians routinely walk more slowly than normal or use wheelchairs in the crosswalk, a walking speed of less than 4.0 ft/s (1.2 m/s) should be considered in determining the pedestrian clearance times. Other research studies have identified pedestrian walking speeds ranging from 2.0 to 4.3 ft/s (0.6 to 1.3 m/s) as discussed in the following sections. The Institute of Transportation Engineers (ITE) *Design and Safety of Pedestrian Facilities* cited walking speeds up to 8 ft/s (2.4 m/s) (*7*).

Pedestrians with Walking Difficulty

A significant proportion (as much as 35 percent) of pedestrians—children, older pedestrians, and persons with disabilities—travels at a slower pace (*8*). Therefore, the slower walking speeds of these groups could be considered when determining pedestrian clearance intervals for traffic signals in locations with a high percentage of pedestrians with walking difficulties. An Australian Institute of Transportation (*9*) study of intersection signalized crossing sites identified the walking speeds of "pedestrians with walking difficulty" (irrespective of age) including older persons, people with disabilities, and parents pushing a baby stroller and/or paying attention to a young child walking alongside, a group which constituted 6 percent of the total sample size. The summary of results is reproduced in Table 3.

Older Pedestrians

In the *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians* report (*10*), an assumed walking speed of 2.8 ft/s (0.9 m/s) is recommended for less capable (15th percentile) older pedestrians with shorter strides, slower gaits, and exaggerated "start-up" times before leaving the curb. Mean start-up time (from the start of the Walk signal to the moment the pedestrian steps off the curb and starts to cross) was 2.5 s for older pedestrians, compared with 1.9 s for younger ones (*8*). A study in Sweden (*11*) found that pedestrians aged 70 or older, when asked to cross an intersection very

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Table 3. Intersection crossing speeds of pedestrians with and without walking difficulty. (*9*)

Average	Speed, ft/s (m/s)	Standard Deviation, ft/s (m/s)	15th Percentile, ft/s (m/s)	50th Percentile, ft/s (m/s)	85th Percentile, ft/s (m/s)
Pedestrians with Walking Difficulty	4.42 (1.35)	0.25 (0.08)	3.74 (1.14)	4.23 (1.29)	5.34 (1.63)
Pedestrians without Walking Difficulty	5.58 (1.70)	0.50 (0.15)	4.27 (1.31)	5.25 (1.60)	6.69 (2.04)
All Pedestrians	5.35 (1.63)	0.48 (0.15)	4.07 (1.24)	5.12 (1.56)	6.43 (1.96)

fast, fast, or at normal speed, considered fast to be less than 4.3 ft/s (1.3 m/s). The comfortable speed was 2.2 ft/s (0.7 m/s) for 15 percent, well below the standard often used.

A design walking speed of 3.3 ft/s (1.0 m/s) has been recommended by Coffin and Morrall (*12*) at crossings used by large numbers of seniors, on the basis of their observations of speeds of older pedestrians at three types of crossings. Speeds were greater at unsignalized intersections than where there were signals. The older people in their study reported difficulty negotiating curbs and judging speeds of oncoming vehicles, as well as confusion with pedestrian walking signal indications (*8*). Results from other studies suggest that a design speed of 3.3 ft/s (1.0 m/s) may be too high.

Pedestrians with Disabilities

According to a study done in the United Kingdom in the 1980s, about 14 percent of individuals over 15 years of age had physical, sensory, or mental handicaps (*13*). This population has become much more mobile in recent decades, and increasing efforts have been made to meet their transportation needs. As expected, the walking speeds for pedestrians with disabilities are lower than the average walking speed assumed for the design of pedestrian crosswalk signal timing (*8*). Table 4 shows some average walking speeds for those with various disabilities and assistive devices.

Weather Conditions

Walking speeds would likely be slowed even further under winter conditions resulting from snow and heavy footwear (*14*). The presence of snow, ice, or slush on sidewalks and roads leads to ill-defined curbs, hidden potholes and obstacles, greater amounts of glare and visual difficulties, and a greater chance of a slip or fall by a pedestrian (especially an older one) (*8*). All these conditions lead to reduced walking speeds during the winter (*14*).

Pedestrians at Signalized Midblock Crossings

A study of pedestrians with walking difficulty at pedestrian-actuated midblock signalized crossings on four-lane undivided roads found an average crossing speed of 4.2 ft/s (1.3 m/s) and a 15th percentile speed of 3.3 ft/s (1.0 m/s), equal to the design speed of 3.3 ft/s (1.0 m/s) recommended by Australian and U.S. design guides for sites with higher populations of slower pedestrians (*15*).

Table 5 summarizes crossing speeds for pedestrians with and without difficulty at midblock signalized crossing sites. Comparison of data in Tables 3 and 5 indicates that crossing speeds are higher at signalized intersections, possibly because of a perception of a less safe environment, especially as a result of turning vehicle conflicts (*9*).

The authors noted that the results of all data for intersection and midblock crossing sites combined indicate that the design speed of 4.0 ft/s (1.2 m/s), commonly used for signal timing purposes, represents the 15th percentile crossing speed, with the corresponding average crossing speed being 4.9 ft/s (1.5 m/s) (*9*).

A similar Australian study that investigated pedestrian movement characteristics at pedestrian-actuated midblock signalized crossings on four-lane undivided roads found the

Table 4. Mean walking speeds for pedestrians with disabilities and users of various assistive devices. (*8*)

Disability or Assistive Device	Mean Walking Speed, ft/s (m/s)
Cane or Crutch	2.62 (0.80)
Walker	2.07 (0.63)
Wheel Chair	3.55 (1.08)
Immobilized Knee	3.50 (1.07)
Below Knee Amputee	2.46 (0.75)
Above Knee Amputee	1.97 (0.60)
Hip Arthritis	2.24 to 3.66 (0.68 to 1.16)
Rheumatoid Arthritis (Knee)	2.46 (0.75)

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Table 5. Midblock crossing speeds of pedestrians with and without walking difficulty. (*9*)

Average	Speed, ft/s (m/s)	Standard Deviation, ft/s (m/s)	15th Percentile, ft/s (m/s)	50th Percentile, ft/s (m/s)	85th Percentile, ft/s (m/s)
Pedestrians with Walking Difficulty	4.23 (1.29)	0.28 (0.09)	3.28 (1.00)	4.30 (1.31)	4.99 (1.52)
Pedestrians without Walking Difficulty	4.75 (1.45)	0.22 (0.07)	4.04 (1.23)	4.72 (1.44)	5.45 (1.66)
All Pedestrians	4.66 (1.42)	0.24 (0.07)	3.87 (1.18)	4.66 (1.42)	5.41 (1.65)

average crossing speed to be 4.7 ft/s (1.4 m/s) and the 15th percentile speed to be 4.0 ft/s (1.2 m/s), very close to the general design speed of 4.0 ft/s (1.2 m/s) recommended by Australian and U.S. design guides.

Pedestrian Start Loss and Clearance Time Gain

Calculating start loss time and clearance time gain are important in determining a pedestrian's effective green time, which is needed to model pedestrian performance measures (e.g., delay, queue length, and number of stops) (*9*). Start loss time is the time lag for stepping on the crossing after the Walk display begins. Clearance time gain is measured as the first part of the pedestrian clearance (Flashing Don't Walk) interval when the pedestrian continues to step on and use the crossing (*9*). Table 6 summarizes pedestrian start loss and clearance time gain values for both intersection and midblock signalized crossing sites and shows similar findings to Table 3 in that start loss values are larger for intersection signalized crossings (possibly due, again, to a perception of a less safe environment) (*9*).

Another study of pedestrians at midblock signalized crossing sites only found the average start loss to be 1.3 s and the average clearance time gain to be 2.9 s, pedestrian movement parameters close to the default values used in the SIDRA 1 software program (1 s and 3 s, respectively) (*15*).

Varying Speeds During a Crossing

One Australian study (*15*) concluded that pedestrian speeds for the first half of the crossing were higher than speeds in the second half, and the average and 15th percentile crossing speeds decrease with increased pedestrian flow rate. Also, crossing speeds and characteristics were similar during the weekdays and weekends.

Pedestrian Space Requirements

A recent study of pedestrian characteristics (*16*) recommends for standing area design a simplified body ellipse of 19.7 in by 23.6 in (50 cm by 60 cm), with a total area of 3.2 ft^2 (0.3 m^2), or roughly 108 percent of the ellipse suggested by Fruin's 1971 study (*17*). This shape (see Figure 1) serves as an approximate equivalent to Fruin's ellipse. This study also recommends a body buffer zone of 8.6 ft^2 (0.8 m^2) for walking, near the upper end of the buffer zone range provided by Pushkarev and Zupan (*18*) and just before "unnatural shuffling" commences.

Washington State's *Pedestrian Facilities Guidebook* (*4*) states that two people walking side by side or passing each other while traveling in opposite directions take up an average space of 4.7 ft (1.4 m) with adequate buffer areas on either side (see Figures 2 and 3). The minimum width that best serves two pedestrians walking together or passing each other is 6 ft (1.8 m).

Table 6. Comparison of pedestrian movement start loss and clearance time gain values for intersection and midblock signalized crossing sites. (*9*)

	Start Loss		Clearance Time Gain		Clearance Time Gain Less Start Loss, s
	Average, s	Standard Deviation	Average, s	Standard Deviation	
Intersection Signalized Crossing Sites					
All Weekdays Combined	2.79	1.57	2.84	2.64	0.05
All Weekends Combined	2.57	1.45	2.05	1.43	-0.52
All Sites Combined	2.68	1.51	3.02	2.31	0.35
Midblock Signalized Crossing Sites					
All Weekdays Combined	1.35	0.57	2.75	2.38	1.40
All Weekends Combined	1.27	0.53	3.08	2.17	1.80
All Sites Combined	1.30	0.55	2.93	2.25	1.60

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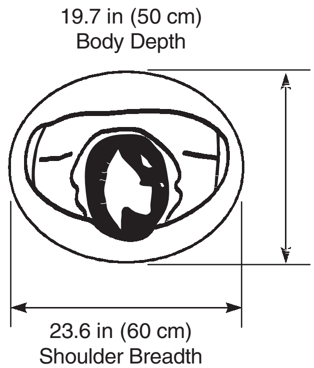

Figure 1. Recommended pedestrian body ellipse dimensions for standing area (16).

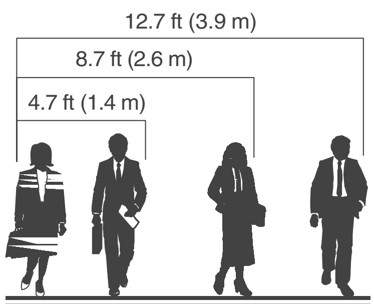

Figure 2. Spatial dimensions for pedestrians (4).

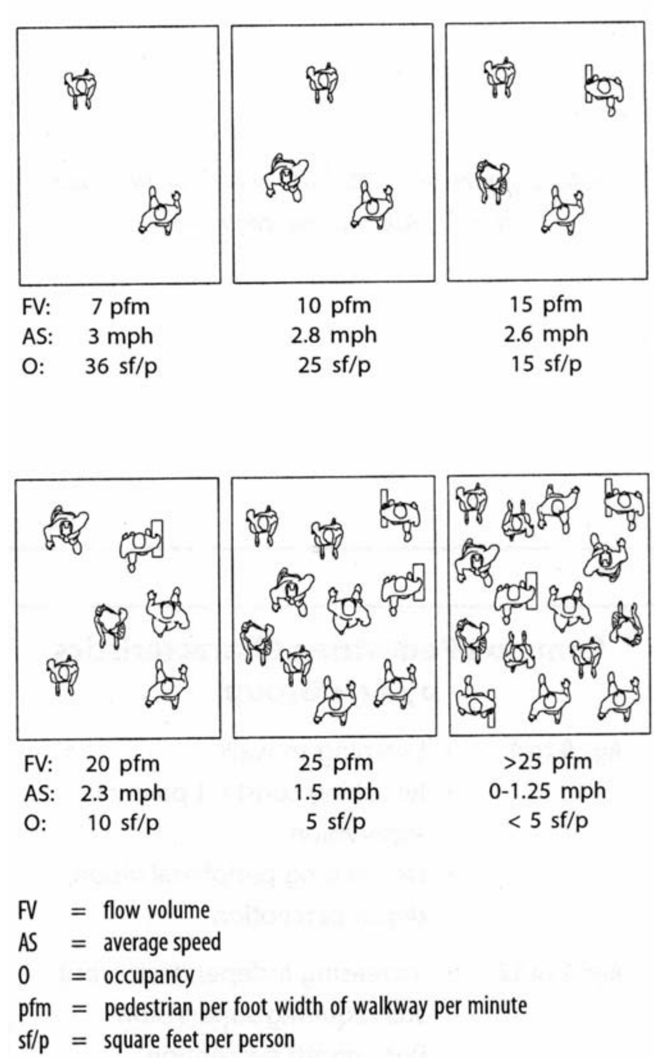

Figure 3. Spatial needs for pedestrians with volume changes (4).

Spatial Bubbles

A spatial bubble is the preferred distance of unobstructed forward vision while walking under various circumstances (*4*). Figure 4 illustrates the special bubbles that are comfortable for the average pedestrian while attending a public event, shopping, walking under normal conditions, and walking for pleasure.

Pedestrians with Disabilities

Space requirements for pedestrians with disabilities vary considerably depending on their physical ability and the assistive devices they use. Spaces designed to accommodate

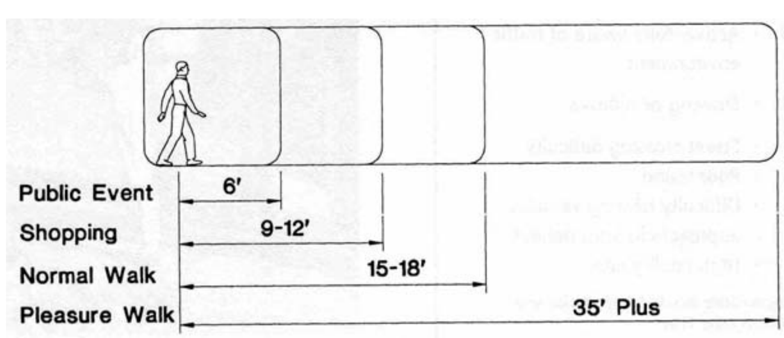

Figure 4. Forward clear space needed by pedestrians (4).

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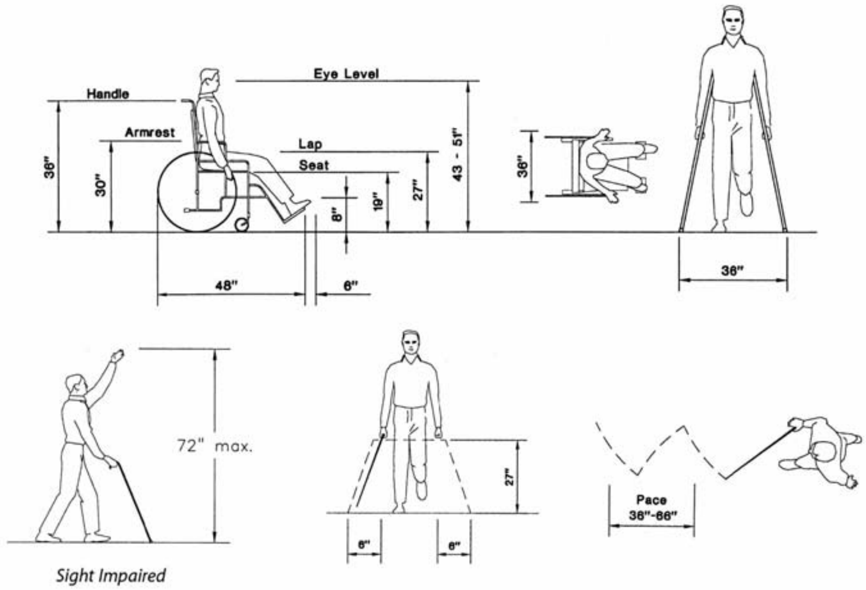

Figure 5. Spatial dimensions for people with disabilities (4).

wheelchair users are generally considered to be functional and advantageous for most people. Figure 5 illustrates the spatial dimensions for a wheelchair user, a person on crutches, and a person with visual impairments.

Pedestrian Capacities

Pedestrians are of all ages and abilities. Table 7 provides highly distinct walking characteristics and abilities for several different groups of pedestrians (*6*).

Use of Signal Stages

An Australian study found that most users (87 percent) crossed during the Walk interval, while the remaining pedestrians crossed during the Flashing Don't Walk or Steady Don't Walk intervals (13 percent) (see Figure 6) (*15*). It appears that improper use of the crossing (crossing outside the Walk interval) and the decision not to use the crossing at all increases with increased pedestrian flow and decreases with increased vehicle flow (*15*).

Pedestrian Waiting Periods

The *Florida Pedestrian Planning and Design Handbook* (*6*) indicates that as a general rule, pedestrians are anxious to get back underway within 30 s. If waiting periods are longer, high school, college, and middle-aged adults, in particular, tend to look for a gap that they can use. In other cases, anticipating a long wait, the same pedestrians tend to cross in other non-signalized locations. The Florida Handbook also indicates that although it is not always practical to reward pedestrians with this short a wait, every effort should be made to keep the wait to the minimum.

Pedestrian Crossing Choices

In one study, researchers developed a model consistent with theoretical expectations of how pedestrians cross roads. The model contains variables descriptive of the street environment including *continuous variables* (such as roadside walking distance, crossing distance, and traffic volume) and *discrete characteristics* (such as the presence of marked crosswalks, traffic signals, and pedestrian signals) (*19*).

The study (*19*) found that people are more likely to cross at an intersection with a traffic signal or a pedestrian signal head (Walk/Don't Walk signs). Also, people are more likely to cross at any location with a marked crosswalk than at those without. As reflected by their coefficients in the model, the relative influences of these discrete characteristics vary among themselves and across options. Specifically, the presence of a marked crosswalk is more influential at an intersection than at a midblock location. For crossings at an intersection, the most influential factors in descending order are pedestrian signals, marked crosswalks, and traffic signals.

An increase in any continuous variable for a given option will result in a decrease in the probability of that option being chosen (i.e., the further a pedestrian has to walk to use a particular crossing option, the less likely it is that the pedestrian will choose that option). The magnitude of the decrease varies across these continuous variables and across options (*19*).

Table 7. Walking characteristics and abilities of different pedestrian groups. (*6*)

Young Children

At a young age, children have unique abilities and needs. Since children this age vary great in ability, it is important for parents to supervise and make decisions on when their child is ready for a new independent activity. Young children

- Can be impulsive and unpredictable,
- Have limited peripheral vision and sound source not located easily,
- Have limited training and lack of experience,
- Have poor gap/speed assessment,
- Think grown-ups will look out for them,
- Think close calls are fun,
- Are short and hard to see,
- Want to run and desire to limit crossing time, and
- Like to copy the behavior of older people.

Preteens

By middle school years, children have many of their physical abilities but still lack experience and training. Now there is greater desire to take risk. Preteens

- Lack experience,
- Walk and bicycle more and at different times (higher exposure),
- Ride more frequently under risky conditions (high traffic),
- Lack positive role models,
- Walk across more risky roadways (collectors and above), and
- Are willing to take chances.

High School Age

By high school and college age, exposure changes and new risks are assumed. Many walk and bicycle under low-light conditions. High school children

- Are very active and can go long distances and to new places;
- Feel invincible;
- Still lack experience and training;
- Are capable of traveling at higher speeds;
- Will overestimate their abilities on hills, curves, etc.;
- Attempt to use bicycles and in-line skates based on practices carried over from youth; and
- Are willing to experiment with alcohol and drugs.

Novice Adults

Adults who have not walked and bicycled regularly as children and who have not received training are ill-prepared to take on the challenges of an unfriendly urban environment. For novice adults,

- 95 percent of adults are novice bicyclists,
- Many are unskilled in urban walking,
- Drinking can influence their abilities,
- Many assume higher skills and abilities than they actually have, and
- Most carry over sloppy habits from childhood.

Proficient Adults

Proficient adults can be of any age. They are highly competent in traffic and capable of perceiving and dealing with risk in most circumstances. Some use bicycles for commuting and utilitarian trips, while others use bicycles primarily for recreation. Proficient adults

- Comprise only 1 to 4 percent of the bicycling population in most communities,
- Tend to be very vocal and interested in improving conditions, and
- May be interested in serving as instructors and task force leaders.

Senior Adults

Senior adults, ages 60 and up, begin a gradual decline in physical and physiological performance, with a rapid decline after age 75. Many are incapable of surviving serious injuries. These changes affect their performance. For seniors,

- They walk more in older years, especially for exercise/independence;
- Many have reduced income and therefore no car;
- All experience some reduction in vision, agility, balance, speed, and strength;
- Some have further problems with hearing, extreme visual problems, and concentration;
- Some tend to focus on only one object at a time;
- All have greatly reduced abilities under low-light-night conditions; and
- They may overestimate their abilities.

Those with Disabilities

Of those who live to an older age, 85 percent will have a permanent disability. Disabilities are common through all ages, and people with permanent disabilities constitute at least 15 percent of the population. Individuals with permanent physical disabilities, often kept away from society in the past, are now walking and bicycling regularly. Many others have temporary conditions, including pregnancy and broken or sprained limbs that may restrict their mobility. This group may include

- Individuals with visual, hearing, mobility, mental/emotional, and/or other impairments;
- Many older adults with reduced abilities;
- Many who were previously institutionalized and are not trained to be pedestrians; and
- Those dependent on alcohol or drugs, who may be hard to recognize.

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Table 7. (*continued*)

Ethnic/Cultural Diversity/Tourism America is rapidly becoming a nation with no clear majority population. All groups need access and mobility in order to fully participate in society. Transportation officials must pay close attention to communication, the creation of ethnic villages, and subcultural needs and practices. Most of these people depend heavily on walking and transit to get around. They include ■ Some newly arriving groups who lack urban experience and ■ Many who are used to different motorist behavior.
Transportation Disadvantaged Thirty to forty percent of the population in most states does not have a car, often because they cannot afford to purchase or operate a car. These men, women, and children depend heavily on walking, transit, and bicycling for their basic freedom, access, and mobility.

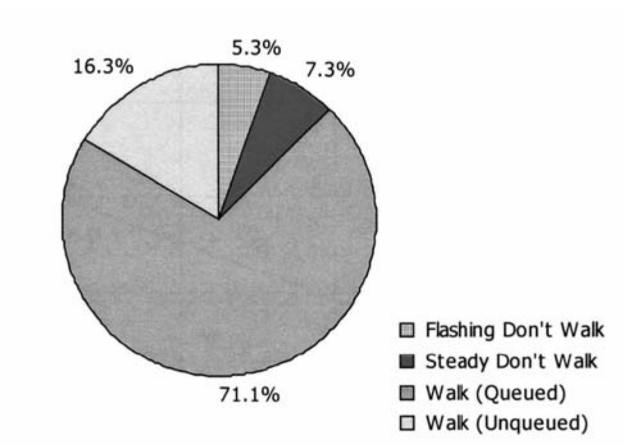

Figure 6. Use of signal stages by pedestrians at midblock signalized crossings (15).

Using survey data (*19*), researchers calculated the probability of the options being chosen in relation to each of the variables. The following are among the conclusions reached:

- Increases in roadside distance (to an intersection) significantly affect a pedestrian's choice to cross at an intersection. The decision to cross at an intersection is little affected, however, by increases in the crossing distance at that intersection.
- Increases in crossing distance are twice as likely to affect jaywalking as increases in traffic volume.
- Crossing midblock is little affected by any of the continuous variables.
- Increases in roadside walking affect crossing at an intersection many times more than crossing midblock.
- Increases in traffic volume affect jaywalking more than crossing midblock.

Child Pedestrians

The characteristics of child pedestrians separate them from the adult pedestrian population and make them a particular concern for roadway designers. Children have a limited concept of rules and why they are needed (until the age of about 10 years), and they often have problems with risk perception, attention, and impulsiveness that make them more vulnerable pedestrians.

An observational study of children's road crossing behavior at a signalized and nonsignalized intersection (*20*) found that well under half of the children who were observed looked in the direction of oncoming traffic before crossing. Slightly more than this looked while crossing and very few looked behind them (to check for turning vehicles) while crossing. A full visual search (looking in both directions before and while crossing and behind while crossing) was carried out by fewer than 5 percent of these observed and by none of the 8- to 12-year-old pedestrians at the signalized crossing.

Children's conceptions of safety are poorly formulated, and their schema for critical behaviors, such as crossing the street, are not well developed. The relatively high accident rate among young pedestrians also relates to the following factors (*8*):

- Children have difficulty with
  - Seeing and evaluating the entire traffic situation correctly as a result of their height
  - Information processing in peripheral vision and poorer visual acuity until about the age of 10 years
  - Distributing their attention and are easily preoccupied or distracted.
  - Discriminating between right and left
  - Correctly perceiving the direction of sound and the speed of vehicles
  - Understanding of the use of traffic control devices and crosswalks
  - Judging distances of cars and when a safe gap occurs between vehicles.
- Many children believe that
  - The safest way to cross the street is to run
  - It is safe to cross against the red light.
  - Adults will always be kind to them, so drivers will be able to stop instantly if they are in danger

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Older Pedestrians

The experiences of older pedestrians differ from those of the young. In general, older pedestrians do not behave as irrationally as do many children and young adults. However, older pedestrians often have physical conditions that limit their abilities to accurately assess the traffic situation. Older people also tend to walk more than others because they have more free time, and walking is good exercise and an inexpensive way to make short trips. The elderly are more law abiding than the general population, and they may, in fact, be too trusting of traffic signals and of drivers when it comes to crossing the streets. They are more likely than younger pedestrians to have accidents due to problems in information processing, judgment, and physical constraints. Other characteristics of older pedestrians follow (*8*):

- Vision is affected in older people by decreased acuity and visual field, loss of contrast sensitivity, and slower horizontal eye movement.
- They often have difficulty with balance and postural stability, resulting in slower walking speeds and increased chances for tripping.
- Selective attention mechanisms and multi-tasking skills become less effective with age, so older people may have difficulty locating task-relevant information in a complex environment.
- They have difficulty in selecting safe crossing situations in continuously changing complex traffic situations, likely because of deficits in perception and cognitive abilities, as well as ineffectual visual scanning, limitations in time sharing, and inability to ignore irrelevant stimuli.
- They have difficulty in assessing the speed of approaching vehicles, thus misjudging when it is safe to cross the road.
- They have slower reaction time and decision making.
- Those with arthritis may have restricted head and neck mobility as well as difficulty walking.
- There is reduced agility for those who use canes or crutches for assistance.

Pedestrian Delay

Depending on the research, pedestrian delay can have different definitions. Most of the studies reviewed defined delay as the amount of time between the point at which a pedestrian arrives at the curbside and the point at which he or she steps off the curb as well as any time that the pedestrian has to wait in the roadway for acceptable gaps in the traffic. One major difficulty with this definition is determining when a pedestrian "arrives" at the curbside. For instance, a pedestrian may walk straight to the curb and then look for a gap in the traffic or he/she may begin to watch for a gap long before stepping up to the curb. In the latter case, the pedestrian can adjust his or her walking speed in which to arrive at the curb at the instant a gap is available in the traffic. Although the pedestrian would experience the same delay as in the first case, the delay may not be counted in a research study.

Another difficulty in determining pedestrian delay arises when pedestrians do not comply with street-crossing guidelines. Pedestrian non-compliance occurs when pedestrians do not use a crosswalk to completely cross a street or when they use a crosswalk incorrectly, such as entering the crosswalk in front of an approaching vehicle. Although greater non-compliance increases the difficulty in determining pedestrian delay, greater pedestrian delay generally increases non-compliance. Most studies state that pedestrians become more likely to take extra risks at longer delays, i.e., above a delay of around 30 s, pedestrians are more likely to accept shorter gaps in traffic through which to cross (*21, 22*).

The *Highway Capacity Manual* (HCM) (*23*) includes average delay to pedestrians at unsignalized intersections as the measure of level of service (LOS) (see Table 8). The table was developed with anecdotal evidence that suggests delay to pedestrians at unsignalized intersections should be considered congruent to delay to vehicles on the cross street at unsignalized intersections. The HCM LOS table for vehicles at two-way stop control is provided as Table 9. The HCM also provides a series of equations to calculate the average delay per pedestrian at an unsignalized intersection. The calculated

Table 8. HCM LOS criteria for pedestrians at unsignalized intersections. (*23*)

Level of Service	Average Delay/Pedestrian (s)	Likelihood of Risk-Taking Behavior*
A	< 5	Low
B	≥ 5 – 10	
C	> 10 – 20	Moderate
D	> 20 – 30	
E	> 30 – 45	High
F	> 45	Very High

* Likelihood of acceptance of short gaps.

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Table 9. HCM LOS criteria for two-way stop control (HCM Exhibit 17-2). (*23*)

Level of Service	Average Control Delay (s/veh)
A	0-10
B	> 10-15
C	> 15-25
D	> 25-35
E	> 35-50
F	> 50

value is to be used in conjunction with Table 8 to determine the level of service of the intersection.

Complicating matters is the belief that non-compliant pedestrians use several tactics when crossing streets. A 1998 FHWA report (*24*) cites a study by Song, Dunn, and Black where all street-crossing tactics were consolidated into four groups: double-gap, risk-taking, two-stage, and walk'n-look. Double-gappers look for an acceptable gap in the near lane as well as a gap twice as long in the far lane through which to cross in one continuous action. Slower or more cautious pedestrians often use this tactic. A pedestrian is said to employ the risk-taking tactic when he or she accepts the same size gap in each lane. Two-stage crossings involve pedestrians who cross one side of the street, take refuge in a median, and then cross the other side of the street. Finally, if a pedestrian does not initially see an acceptable gap in the traffic, he or she may walk down the side of the street while constantly looking for an acceptable gap through which to cross. This tactic is known as the walk'n-look and is perhaps the most efficient, greatly reducing or removing the delay to the pedestrian wishing to cross the street. However, it is not useful when the pedestrian's main travel objective is perpendicular to the street.

Pedestrian delay increases as vehicular traffic volumes increase. As pedestrian volumes increase, however, a precedent is established whereby motorists begin to expect pedestrians. At these locations, drivers are more likely to yield to pedestrians, which in turn decreases pedestrian delay (*25*).

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CHAPTER 3

Review of Pedestrian Crossing Treatments

Initial research efforts were to review available information on pedestrian crossing treatments and designs. Several recent publications provide a good overview on various crossing treatments, including the following:

- 2001 ITE informational report on *Alternative Treatments for At-Grade Pedestrian Crossings* (*26*) and
- 2002 FHWA report on *Pedestrian Facilities Users Guide* (*27*).

The findings identified in this project from recent research are documented in the following appendixes:

- Appendix C presents the literature review.
- Information on current practices since the 2001 ITE report is included in Appendix D.
- Each study in the literature review is discussed in Appendix E.
- Appendix F discusses pedestrian crossing installation criteria used by entities in several countries. Criteria identified during this joint TCRP/NCHRP project is summarized at the end of the appendix.

This chapter summarizes the major evaluation findings for various pedestrian crossing treatments at uncontrolled locations and provides the research team's interpretation of these findings.

Combinations of Treatments

Several evaluations have tested a combination of crossing treatments and found these treatments to be more effective when used together systematically. For example, a study in St. Petersburg, Florida, found that advanced yield lines, Yield Here to Pedestrian signs, and pedestrian prompting signs were most effective when used together (*28*). The research team believes that the safest and most effective pedestrian crossings often use several traffic control devices or design elements to meet the information and control needs of both motorists and pedestrians.

For example, consider the following desirable characteristics for a pedestrian crossing:

- The street crossing task is made simple and convenient for pedestrians.
- The crossing location and any waiting or crossing pedestrians have excellent visibility.
- Vehicle speeds are slowed or controlled in the area of the pedestrian crossing.
- Vehicle drivers are more aware of the presence of the crosswalk.
- Vehicle drivers yield the right-of-way to legally crossing pedestrians.
- Pedestrians use designated crossing locations and obey applicable state and local traffic laws.

In a complex (e.g., multi-lane, high-speed, high-volume) street environment, it probably will be difficult to provide these characteristics with a single simple treatment, i.e., complex street environments may require several different treatments intended to serve different purposes. For example, one might consider these treatments on a multi-lane, high-volume arterial street:

- A median refuge island to make the street crossing easier and more convenient;
- Advanced yield lines to improve the visibility of crossing pedestrians;
- Removal of parking and installation of curb extensions to improve visibility;
- Pedestrian-activated flashing beacons to warn motorists of crossing pedestrians;
- Motorist signs to indicate that pedestrians have the legal right-of-way;

- Pedestrian signs to encourage looking behavior, crosswalk compliance, and pushbutton activation;
- In-pavement warning lights with advance signing to inform drivers of the crossing; and
- “Countdown signals” with a pedestrian (Walk/Don’t Walk) signal if appropriate for the treatment (e.g., high-intensity activated crosswalk [HAWK] signal or other pedestrian traffic control signals).

Streets with lower speeds or traffic volumes may not require multiple treatments to be safe and effective. In these less complex street environments, single treatments may be just as safe and effective as multiple treatments.

Traffic Signal and Red Beacon Displays

Pedestrian devices that include a red signal indication vary. These devices include traffic signals and displays with solid or flashing red beacons. There is limited experience with intersection pedestrian signals (commonly known as “half signals”) because their current operation is limited to a few cities (e.g., Seattle and Portland). They are also used in some provinces of Canada (British Columbia being the most notable).

For vehicle control, these pedestrian signals typically use a traditional traffic signal head on the major street and a Stop sign on the minor street (if applicable). Midblock pedestrian signals are used in Europe (as well as Canada and the United States), where they are referred to as pedestrian crossovers (Toronto) or pelicans or puffins (Europe). Pedestrian movements across the major street are controlled by traditional pedestrian Walk/Don’t Walk signals for red signal indication devices.

The signal display sequences for these pedestrian signals vary among installations. Half signals in the city of Seattle dwell in steady green and then cycle to steady yellow and then steady red when activated by a pedestrian. The HAWK signals in Tucson (see Figure 7) are modeled after emergency vehicle beacons and are dark until activated by a pedestrian; then they cycle through flashing yellow, steady yellow, steady red, and then flashing red. Half signals in the Vancouver area of British Columbia dwell in flashing green and, on activation, steady green (for some installations), steady yellow, and then steady red. The midblock pedestrian signal in Los Angeles shows a green arrow, cycles to a steady yellow, and then cycles to steady red during the walk interval. During the flashing Don’t Walk interval, drivers see a flashing red indication and, after stopping, may proceed if the crosswalk is not occupied.

Despite differences in signal operation, the pedestrian or half signals have been documented as successful in encouraging motorists to yield to pedestrians along high-volume and/or high-speed streets. For example, several studies (*28-30*), including the study done for this TCRP/NCHRP project (see Appendix L), have documented driver yielding in the 90 to 100 percent range. The steady red signal indication provides a clear regulatory message that typically receives a more uniform control response than warning signs or flashing beacons. Critics of the concept have suggested that vehicle crashes will increase because of signalization on the major street or conflicting control messages from the signal and Stop sign. However, crash analyses in the city of Seattle have documented that, with consistent operation, the half signals can actually reduce vehicle-vehicle crashes and pedestrian-vehicle conflicts (*31-34*). Inconsistent and somewhat confusing operation (e.g., flashing green) of half signals in British Columbia has generated poor compliance with Stop signs on the minor street (*35*).

Figure 7. HAWK signal in Tucson, Arizona.

In summary, devices with a red signal indication show promise as a pedestrian-crossing treatment for high-volume, high-speed arterial streets. The field studies conducted in this project indicated that these red signal or beacon devices were most effective at prompting motorist yielding (all sites had motorist compliance greater than 90 percent) on high-volume, high-speed streets. It may be necessary to determine the most effective signal indication display sequence, as well as the traffic conditions that would accommodate the use of minor street Stop sign control and major street signal control.

Flashing Beacons

The use of flashing beacons for pedestrian crossings is prevalent in the United States (see Figure 8). In some instances, there are concerns that the overuse of flashing beacons or the continuous flashing at specific locations has

Figure 8. Pedestrian-activated overhead flashing beacon.

diluted their effectiveness in warning motorists of conditions. Flashing beacons have been installed in numerous ways:

- At the pedestrian crossing, both overhead and side mounted;
- In advance of the pedestrian crossing, both overhead and side mounted;
- In conjunction with or integral within other warning signs; and
- In the roadway pavement itself (see next section on in-roadway warning lights).

The operations for flashing amber beacons may also vary, including the following:

- Continuous flash mode;
- Pedestrian activated using manual pushbuttons;
- Passive pedestrian detection using automated sensors (e.g., microwave or video); and
- Different flash rates, sequences, or strobe effects.

The experience with flashing beacons has been mixed, as would be expected when they have been installed in numerous different ways. Several studies have shown that intermittent (typically activated using a manual pushbutton or automated sensor) flashing beacons provide a more effective response from motorists than continuously flashing beacons (*36, 37*). These beacons do not flash constantly; thus, when they are flashing, motorists can be reasonably sure that a pedestrian is crossing the street. With pedestrian activation, special signing may be necessary to ensure that pedestrians consistently use the pushbutton activation. Alternatively, automated pedestrian detection has been used with some success, but typically requires extra effort in installation and maintenance.

Overhead flashing beacons appear to have the best visibility to motorists, particularly when used both at and in advance of the pedestrian crossing. Many installations have used both overhead and side-mounted beacons. The effectiveness of the flashing beacons in general, however, may be limited on high-speed or high-volume arterial streets. For example, overhead flashing beacons have produced driver yielding behavior that ranges from 30 to 76 percent, with the median values falling in the mid-50 percent range (*26, 36-38*). The evaluations did not contain enough information to attribute high or low driver yielding values to specific road characteristics. The field studies conducted in this TCRP/NCHRP project found a similarly wide range of motorist yielding values (25 to 73 percent), with the average value for all flashing beacons at 58 percent. The analysis of site conditions and traffic variables also found that traffic speeds, traffic volumes, and number of lanes have a statistically significant effect on driver yielding behavior on arterial streets.

In-Roadway Warning Lights

As a specific design case of flashing beacons, in-roadway warning light installations have proliferated in their 10 years of existence. Their use originated in California and Washington State but has spread to numerous other places in the United States (see Figure 9). In-roadway warning lights are mounted in the pavement near the crosswalk markings such that they typically protrude above the pavement less than 0.5 in (1.3 cm). As with flashing beacons, the experience with in-roadway warning lights has been mostly positive, with a few negative results.

Many early and some current equipment designs for the in-roadway warning lights have been problematic. Some of the problems encountered are as follows:

- Snow plows have damaged the flashing light enclosures,
- Light lenses have become dirty from road grit and have required regular cleaning, and
- Automated pedestrian detection has not operated effectively.

Figure 9. In-roadway warning lights and supplemental signs and beacons in Austin, Texas.

Many of the early problems have been resolved through the past 10 years of experience, but some cities continue to be cautious in specifying more in-roadway warning lights until they have long-term experience. Some cities have noted their preference for overhead flashing beacons instead of in-roadway lights because of poor visibility issues when traffic is queued in front of the in-roadway lights (*37, 39*). Another concern is that in very bright sunlight, the flashing lights are difficult for drivers to see.

For most of the installations, in-roadway warning lights have increased driver yielding to the 50 to 90 percent range (*38, 40-44*). Additionally, the in-roadway warning lights typically increase the distance that motorists first brake for a pedestrian crossing, indicating that motorists recognize the pedestrian crossing and the need to yield sooner (*40-43*). These results have been even more dramatic at night when the in-roadway warning lights are highly visible. For a few installations, driver yielding decreased or did not increase above 30 percent (*38, 45*). The research team hypothesizes that these installations were most likely inappropriate and other crossing treatments would have been more effective. The research team did not include in-roadway warning lights in this TCRP/NCHRP project's field studies because of the abundance of evaluation results in the literature.

Motorist Warning Signs and Pavement Markings

Motorist warning signs and pavement markings used as pedestrian crossing treatments can take many shapes and forms; examples are as follows:

- Animated or roving eyes,
- Advance yield or stop lines,
- Crossing flags carried by pedestrians (see Figure 10),
- Yield to Pedestrian and Stop Here for Pedestrian signs, and
- Internally illuminated crosswalk signs.

The experience with these types of warning signs and pavement markings has generally been modest, with a few treatments showing more promise than others. The strength of the message that these traffic control devices sends to motorists is mostly considered a warning (i.e., "watch out for pedestrians" or "avoid pedestrians"). In many cases, the research team hypothesizes that motorists receive these warning messages and consider yielding or stopping for pedestrians as a courtesy and not the law (it is the law in many states). The research team further hypothesizes that motorists are less willing to extend this "courtesy" to pedestrians on high-speed, high-volume roadways because they think (1) they are being delayed unnecessarily and (2) these high-speed, high-volume roadways are the domain of automobiles and not pedestrians.

Figure 10. Pedestrian crossing flags in Salt Lake City, Utah.

As indicated, several of the crossing treatments show more promise than others. Advance yield lines place the traditional stop or yield line 30 to 50 ft (9.1 to 15.2 m) in advance of the crosswalk and are often accompanied by Yield Here to Pedestrian signs. Advance yield lines address the issue of multiple threat crashes on multi-lane roadways, where one vehicle may stop for a crossing pedestrian but inadvertently screens the pedestrian from the view of vehicles in other lanes. Several studies have documented that advance yield lines decrease pedestrian-vehicle conflicts and increase driver yielding at greater distances from the crosswalk (*28, 46-48*).

In-street pedestrian crossing signs and high-visibility signs and markings were two types of treatments included in this TCRP/NCHRP project's study sites. The field studies indicated that in-street signs had relatively high motorist yielding (ranged from 82 to 91 percent, for an average of 87 percent); however, all three study sites were on two-lane streets with posted speed limits of 25 or 30 mph (40 or 48 km/h). The results for high-visibility signs and markings also demonstrated the effects of higher posted speed limits. One site with high-visibility signs and markings and a posted speed limit of 25 mph (40 km/h) had a motorist yielding value of 61 percent.

However, the other two study sites with high-visibility signs and markings and a posted speed limit of 35 mph (55 km/h) had motorist yielding values of 10 and 24 percent, for an average of 17 percent.

Several cities (e.g., Salt Lake City, Utah; Kirkland, Washington; and Berkeley, California) use fluorescent orange flags that are carried by crossing pedestrians. The research team found no formal studies in the literature on the effectiveness of crossing flags; however, anecdotal information has indicated that these crossing flags are effective in improving driver yielding behavior. The flags in Salt Lake City are used mostly on streets near the downtown area that have speed limits of 30 mph (48 km/h) or less. Several of these streets, however, are multi-lane, high-volume arterials. Field studies conducted in this TCRP/NCHRP project found pedestrian crossing flags in Salt Lake City and Kirkland to be moderately effective. The study sites with crossing flags had motorist yielding rates that ranged from 46 to 79 percent, with an average of 65 percent compliance. Several of the study sites had four or more lanes with speed limits of 30 mph (48 km/h) or 35 mph (55 km/h).

Crosswalk Pavement Markings

Until recently, a San Diego study from the early 70s has served as the authoritative reference on marked crosswalks (*49*). The San Diego study indicated that nearly six times as many crashes occurred in marked crosswalks as in unmarked crosswalks. After accounting for pedestrian usage, the crash ratio was reduced to about two to three times as many crashes in marked crosswalks as in unmarked crosswalks. Some engineers interpreted these results to mean that they should install fewer crosswalks (i.e., not mark crosswalks) for pedestrian crossings than more (e.g., install treatments such as flashing beacons, advanced yield lines, and median refuge islands, in addition to pavement markings).

In a 2002 study by the Highway Safety Research Center (HSRC), the authors found the crash experience of marked versus unmarked crosswalks at 1,000 locations in 16 states comparable with the San Diego results (*50*). After adjusting for various traffic and pedestrian characteristics, the authors found that the risk of a pedestrian-vehicle crash was 3.6 times greater at uncontrolled intersections with a marked crosswalk than with an unmarked crosswalk. However, the authors took the study results one step further by producing a matrix that indicates under what conditions (i.e., geometry, speed, and traffic volume) marked crosswalks alone are insufficient and other pedestrian crossing improvements are needed. Thus the 2002 HSRC study does not leave interpretation of the results open but instead suggests more crossing improvements in certain multi-lane, high-volume, high-speed roadway environments.

Other studies have confirmed the higher crash rates at marked versus unmarked crosswalks (*51, 52*). A study of 104 locations in Los Angeles indicated that removing marked crosswalks reduced the total number of vehicle-pedestrian crashes at the formerly marked crosswalks as well as nearby unmarked crosswalks (*51, 52*). This result suggested that pedestrian-vehicle crashes were not simply being moved to nearby unmarked crosswalks when marked crosswalks were removed.

Two studies have suggested that speeds are lower at locations with crosswalk pavement markings (*53, 54*). However, the documented speed reductions were so small (e.g., 0.2 to 2 mph [0.32 to 3.2 km/h]) as to be practically negligible. These studies also found that blatantly aggressive pedestrian behavior did not increase with installation of pavement marking; however, the studies did not address basic looking behavior that would indicate a decrease in pedestrian attentiveness while crossing at marked versus unmarked crosswalks.

Roadway Design Elements

Several other design elements are considered effective at pedestrian crossings, including median refuge islands, curb extensions, and adequate nighttime lighting. In many cases, these design elements are used in conjunction with other crossing treatments as described above. For example, median refuge islands are considered very effective for pedestrian crossings on multi-lane streets. The 2002 HSRC crosswalk study found that multi-lane streets with median refuge islands had pedestrian crash rates two to four times lower than multi-lane streets without median refuge islands (*50*). The field studies from this TCRP/NCHRP project indicated a wide range of motorist yielding at study sites with median refuge islands and marked crosswalks. For six sites, the motorist yielding ranged from 7 to 75 percent, with an average of 34 percent. As with other pedestrian crossing treatments, the number of through lanes and posted speed limit were statistically significant in explaining the wide range of effectiveness (as measured by motorist yielding). Curb extensions improve the visibility of pedestrians waiting to cross, as well as decrease their exposure by decreasing the crossing distance and time. Adequate nighttime lighting better illuminates crossing pedestrians as well as the crossing itself.

Summary

Numerous engineering treatments and design elements can be used to improve pedestrian crossings along high-volume, high-speed roadways. In a literature review, the research team found that a combination of crossing treatments is likely to be more effective in meeting the information and control needs of pedestrians and motorists. For example, the following might be appropriate along a high-volume, multi-lane arterial street: median refuge island, advanced yield lines, curb extensions with parking restrictions nearby, overhead flashing beacons, and high-visibility motorist and pedestrian signs. The literature review revealed that several experimental traffic control devices that display red signal or beacon indications were effective at prompting motorist compliance and increasing pedestrian safety. Evaluations of other traffic control devices that provide a warning (e.g., signs and flashing beacons or lights) had wide ranges of effectiveness, with wider, busier streets having lower motorist compliance with marked crosswalks. The field studies conducted for this TCRP/NCHRP project supported the main findings from the literature review, in that red signal or beacon devices were more effective than all other devices evaluated, with motorist compliance values between 90 and 100 percent at all study sites. With other warning devices, the research team found a wide range of motorist compliance values. Further, the analysis found that the number of lanes and posted speed limit were statistically significant in explaining part of this wide range in treatment effectiveness.

CHAPTER 4

Review of Pedestrian Signal Warrant

This chapter summarizes the research team's review and critique of the existing MUTCD pedestrian traffic signal warrant. Details on reviews conducted on the pedestrian signal warrant are included in the following appendixes:

- Appendix G summarizes international signal warranting practices.
- Appendix H summarizes the basis for and use of the MUTCD pedestrian signal warrant.
- A workshop was held to explore the use of engineering judgment in evaluating intersections to determine if a signal should be considered. The details of the workshop efforts are documented in Appendix I.

The recommendations for changes to the pedestrian signal warrant submitted to the National Committee on Uniform Traffic Control Devices in June 2005 and January 2006 are in Appendix B. The development of those recommendations, along with the pedestrian treatment guidelines (which use the signal warrant criteria as part of the guidelines) is discussed in Appendix O. A summary of the critique of the MUTCD pedestrian signal warrant follows.

Review of Current Pedestrian Signal Warrant

The current MUTCD pedestrian signal warrant (Warrant 4) has many factors to be considered when evaluating whether or not a signal is warranted. For this TCRP/NCHRP project, these factors were split into three levels: primary factors, secondary factors, and not related to current research study. These levels reflect the type of requirement as indicated in the language of the MUTCD and the relevance to the issue being studied. Primary factors must be considered and include available vehicular gaps (based on critical gap), pedestrian volume, and distance to the nearest traffic signal. A secondary factor is walking speed, which is used to adjust pedestrian volumes.

Despite the wide range of factors included in the current pedestrian signal warrant, other factors could be considered. For example, a correlation between acceptable gap criteria and factors such as pedestrian age, pedestrian vision (and walking) abilities, vehicle speed, and roadway cross section is reasonable. Also, the warrant does not mention safety considerations. Particularly critical to this project, there is no consideration of pedestrian generators, such as transit stops, within the warranting criteria. There are also no allowances for pedestrian volumes that could result from the installation of pedestrian-friendly treatments. Pedestrian delay is the measure used in the HCM (*23*) to determine the level of service for pedestrians. Delay is not directly considered in the signal warrant; however, it relates to other variables such as pedestrian volume and gaps.

Other attributes of the warrant could be a reference to alternative means of traffic control and how to determine the size of the adequate gap length. The guidance section of the MUTCD could be expanded to note that if a signal is not warranted, then less restrictive controls may be appropriate, for example, in-roadway warning lights. Information on how to calculate critical gaps could provide the user with the preferred method for determining the value. The *Highway Capacity Manual* has a method to calculate critical gap for a single pedestrian or a group critical gap in Chapter 18 and could be referenced (*23*).

The following summarizes the key factors introduced above. Additional details are provided in Appendix H.

Primary and Secondary Factors

Primary and secondary factors include the following:

- **Vehicular Gap**. The gap criterion was introduced in 1988. The criterion was derived from ITE's school crossing guidelines (dating back to 1962). The guidelines were based on an old but common traffic signal timing scheme of fixed 60-s cycles. It is very difficult to maintain 60-s cycle lengths because of pedestrian phasing and left-turn phasing.

- **Pedestrian Volume**. The current pedestrian volumes are higher than most of the previous research recommendations, which were developed based on different factors. Comparing the pedestrian volumes included in Warrant 4 with the vehicular volumes in other warrants reveals some interesting trends. Warrant 2 considers minor road traffic volume for 4 hours, while Warrant 3 considers minor road traffic volume for the peak hour. Warrant 4, which uses pedestrian values, also includes peak hour and 4-hour criteria. A difference is that only one "minor approach" value is provided in Warrant 4 rather than the sliding scale present in Warrants 2 and 3. In other words, as the major street volume increases in Warrants 2 and 3, the needed minor street volume to warrant a signal decreases. For the pedestrian warrant, a single "minor approach" value is provided. A second difference is that the vehicle warrants include a reduction factor for population and major roadway speed while the pedestrian warrant does not. Another difference is the minimum number of vehicles or pedestrians needed to warrant a signal. A comparison of the lower threshold volumes is shown in Table 10. For example, an intersection with only 100 vehicles for the peak hour would warrant a signal before a midblock location with 143 pedestrians per hour. When the 70 percent factor is used, the difference becomes even more pronounced. An intersection could warrant a signal with only 75 vehicles while 143 pedestrians would still be required. This comparison assumes a high number of vehicles on the major road; however, it does demonstrate a difference between vehicles and pedestrians.
- **Distance to Nearest Traffic Signal**. The current warrant includes a provision that a signal shall not be considered at locations within 300 ft (91 m) of another signal. This is believed to be based on the distance a pedestrian will walk in order to cross the major street. The researchers did not identify data that support this distance or other distances of how far beyond the desired path a pedestrian would be willing to walk. The U.S. DOT's 1995 Nationwide Personal Transportation Survey did find that most pedestrian trips (73 percent) are 0.5 mi (0.8 km) or less (*3*). With most trips being about 2,600 ft (792 m), pedestrians might not be willing to increase their trip length by more than 10 percent in order to walk to a different crossing location. As part of the on-street pedestrian surveys documented in Appendix K, those interviewed were asked "if this crossing was not here, would you walk to the next intersection (*point to intersection of interest*)?" For three of the sites, only about 25 percent of the respondents would walk to a signalized intersection at 550, 950, or 1,000 ft (168, 290, or 305 m). For the site with a signalized intersection about 200 ft (61 m) from the crossing, about 50 percent of those interviewed would walk to that crossing. The remaining site where this question was appropriate did not follow similar findings. A much higher percentage indicated that they would be willing to walk to another crossing. Over 65 percent of the respondents indicated that they would walk 600 ft (183 m) to cross at a signalized crossing. The greater

Table 10. Comparison of vehicle and pedestrian threshold values.

Condition	Number of Lanes on Minor Road Approach	Lower Threshold Volume (Pedestrian or Vehicle on Highest Volume Minor Road Approach)			
		Peak Hour		Four Hour	
		Warrant 3 [b] Vehicular (vph)	Warrant 4 [c] Pedestrian (ped/h)	Warrant 2 [d] Vehicular (vph)	Warrant 4 [e] Pedestrian (ped/h)
Warrant	2 or more	150	143	115	75
	1	100		80	
70% Factor [a]	2 or more	100	143	80	75
	1	75		60	

[a] For communities less than 10,000 population or above 40 mph (64 km/h) on major street. Only applies to Warrants 2 and 3.
[b] The minimum minor road volume occurs when the major street volume is approximately 1,450 veh/h or at 1,050 veh/h when the community is less than 10,000 or the speed on the major road exceeds 40 mph (64 km/h).
[c] Warrant 4 requires 190 ped/h crossing the major road in the peak hour. To compare with Warrant 3, this value was adjusted to a highest approach value by assuming a 75/25 directional distribution split.
[d] The minimum minor road volume occurs when the major street volume is approximately 1,050 veh/h or more or at 750 veh/h when the community is less than 10,000 or the speed on the major road exceeds 40 mph (64 km/h).
[e] Warrant 4 requires 100 ped/h crossing the major road during 4 h. To compare with Warrant 2, this value was adjusted to a highest approach value by assuming a 75/25 directional distribution split.

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number of individuals willing to walk such a distance was influenced by the number of lanes at the site (six lanes), speed and volume of traffic (high), and existing treatment (marked crosswalk only). Several of the respondents selected "yes" to the question and then commented that they walk to the nearby crossing "most of the time" or "sometimes" depending on the weather or other factors.

- **Reduction Criteria Based on Walking Speeds.** In the current warrant, the only reduction factor is based on walking speed, and it only affects the pedestrian volume criterion. This reduction factor was introduced in order to accommodate older pedestrians and persons with disabilities. Specifically, if the average walking speed is less than 4 ft/s (1.2 m/s), then a reduction of the pedestrian volume of up to 50 percent can be implemented. Chapter 6 and Appendix M include recommendations on walking speeds based on the research conducted as part of this TCRP/NCHRP study.

Potential Factors

Potential factors include the following:

- **Pedestrian Generators (Transit Stops).** The closeness of a pedestrian generator is not considered within the current pedestrian signal warrant.
- **School Warrant.** The school signal warrant has a unique feature that may lend itself to the handling of all pedestrian crossing treatments. In the school warrant, the main consideration is the ratio of the number of adequate gaps to the number of minutes the crossing is being used. This ratio could be used to set thresholds for various crossing treatments.
- **Crash Experience.** As indicated in Appendix G, other countries use crash experience to justify the installation of a traffic signal. The MUTCD includes a crash experience warrant, but it is focused on vehicular crashes. Including a factor in the warranting criteria that considers safety in terms of pedestrian-related crashes, especially because of the vulnerability associated with pedestrian crashes, may be reasonable.
- **Counting Pedestrians on the Minor Approach with Vehicular and Bicycle Volumes.** Other research has recommended more global changes to the way pedestrians are handled in the signal warranting criteria (*55*). The recommendations include counting pedestrians on the minor approaches as vehicles and bicycles are counted now, which would change the vehicular-based warrants to all-mode, intersection-based warrants and would allow the pedestrian warrant to focus on just the midblock crossing, which would make the warrant more straightforward. The largest issue to be considered is how to count pedestrians versus vehicles. The pedestrians are exposed to inclement weather conditions, have slower acceleration and speed rates resulting in longer crossing times, and are at considerably more risk than occupants of vehicles, especially as the major street speeds increase. Therefore, developing an equivalency factor for pedestrians at intersections seems reasonable. Critical gaps for vehicles and pedestrians are provided in the Highway Capacity Manual and the AASHTO Green Book (*23, 56*). Table 11 lists the critical gaps to cross a sample roadway. A pedestrian requires more time to cross an intersection than does a vehicle. To cross a two-lane roadway, a pedestrian needs 39 percent more time (factor of 1.4) than does a vehicle. At a four-lane street, a pedestrian needs twice as much time (or a factor of 2.0) than does a vehicle. Canada's pedestrian signal procedure includes equivalent adult units with children and those with disabilities counting as 2.0 adults and seniors counting as 1.5 adults. The concept of counting all road users on the minor street approach is not novel to the MUTCD. The current MUTCD multi-way Stop warrant has a criterion that includes the summation of vehicles, bicycles, and pedestrians on the minor street approach.
- **Vehicle Speed.** Most of the current vehicular-based traffic signal warrants include a reduction factor based on the speed of the vehicles on the major street. The pedestrian signal warrant also included the same reduction factor until the 1988 revision.
- **Pedestrian Delay.** The HCM includes a procedure to estimate pedestrian delay for an unsignalized intersection. The average delay of pedestrians at an unsignalized intersection crossing depends on the critical gap, the vehicular flow rate of the subject crossing, and the mean vehicle headway. The HCM Exhibit 18-13 (reproduced as Table 12) is then used to determine the LOS of the crossing. A signal warrant could be developed based on a function of the pedestrian delay.

Table 11. Critical gaps for vehicles and pedestrians at an unsignalized intersection.

Through Lanes	Critical Gaps	
	Vehicle (s)	Pedestrians (s)
2	6.5	9.0
4	7.5	15.0
Source	Green Book Exhibit 9-57, assume passenger car	HCM Equation 18-17, assume 12-ft (4-m) lanes, 4 ft/s (1.2 m/s) walking speed, and 3-s start up

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Table 12. Reproduction of HCM Exhibit 18-13: LOS criteria for pedestrians at unsignalized intersections. (*23*)

LOS	Average Delay/Pedestrian(s)	Likelihood of Risk-Taking Behavior [a]
A	< 5	Low
B	≥ 5 to10	
C	> 10 to 20	Moderate
D	> 20 to 30	
E	>30 to 45	High
F	> 45	Very High

[a] Likelihood of acceptance of short gaps.

Findings From the Workshop

The MUTCD traffic signal warrants were developed with "a careful analysis of traffic operations, pedestrian, and bicyclist needs, and other factors at a large number of signalized and unsignalized intersections, coupled with engineering judgment." Research projects are periodically conducted to ensure that the traffic signal warrants reflect current operational and safety needs for the different user groups. In addition to researching operational and safety needs, periodic reviews of engineers' judgment toward the traffic signal warrants (or toward proposed revisions to the traffic signal warrants) are needed.

A study (*55*) in Texas recruited six DOT representatives, seven city representatives, and one consultant representative (all from Texas) to assess the appropriateness of installing a traffic signal because of pedestrian concerns at five locations. The Texas study provided interesting findings; however, only using engineers from one state was a concern. For this TCRP/NCHRP study, the timing and location of the 2004 Institute of Transportation Engineers Spring Conference provided an opportunity to host a workshop on engineering judgment evaluations of pedestrian signal warrants that could include a more diverse geographic representation. The workshop was held March 28, 2004, in southern California. The workshop's objectives were to obtain opinions on

- The traffic signal warrants;
- How they related to specific locations; and
- Potential treatments, including signalization, for the selected intersections.

Workshop Procedures

The Signal Warrant Engineering Judgment Evaluation Workshop was held March 28, 2004. Two tours were conducted as part of the workshop. In the first tour, seven engineers participated; six participated in the second. Each tour included an engineer who was very familiar with the area and could answer questions about local practices. Of the 13 participants, 9 participants came from the West Coast, one came from the Northwest, one came from the East Coast, and two came from the Midwest.

Each participant was provided with traffic/pedestrian data, photographs, and a sketch of the eight intersections. The traffic volumes were provided both in numeric format and plotted on a chart with the relevant curves for Signal Warrant 2 (4-hour vehicular volume) and Warrant 3 (peak hour). Tables were also provided listing the pedestrian volume (per hour and per street), intersection characteristics, and preliminary results from an analysis using the eight warrants.

The group then drove to each site and reviewed the conditions in the field. While in the field, the participants completed a questionnaire for each site. After visiting the eight sites, the tour concluded at the original hotel with a 1-hour discussion. The discussion included comments on specific sites as well as general discussion on the pedestrian signal warrant. The participants were also asked to complete a general questionnaire on the pedestrian signal warrant.

Workshop Observations

Details on the workshop and findings are included in Appendix J. Observations from the workshop are summarized below

- **The revised pedestrian signal warrant should consider the width of roadway being crossed.** The width could either be the number of lanes or width of the roadway; however, if the number of lanes is being used, then a method to factor in the presence of bike lanes, parking lanes, and/or center turn lane needs to be included (given that all represent extra distance that a pedestrian must consider and cross). The judgment decision and gap determination become more difficult when a pedestrian is crossing a wider street.
- **The pedestrian signal warrant needs to consider the number of vehicles on the roadway along with the number of pedestrians.** When there are many pedestrians and few cars, the pedestrians can "control" the crossing by becoming a steady stream of pedestrians with insufficient gaps for vehicles to enter (for example, a site where there

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was heavy pedestrian movement between a parking garage and a municipal building in the morning and afternoon). In this situation, a signal is not needed for the pedestrian (although one participant noted that a signal may be needed for the vehicles–i.e., the signal needs to stop the pedestrians to allow the cars to move through the crossing). The participants preferred having the vehicle data expressed in number of vehicles rather than gaps.

- **The revised warrant should consider the operating or posted speed on the major roadway**.
- **Several participants commented on treating pedestrians and vehicles equally.**
- **One participant noted a safety concern with crosswalks on streets with four or more lanes.** These crosswalks have the potential for a "multiple threat" conflict, where a pedestrian begins to cross in front of a vehicle stopped in the near lane but then has to avoid a vehicle in a subsequent lane that has not stopped. The participant advocated a different set of criteria for pedestrian signals on multi-lane streets.
- **The participants considered the following factors during the evaluation of the eight intersections:**
  - Pedestrian volume (92 percent);
  - Traffic volume (77 percent);
  - Speed (operating or posted) on major street (46 percent);
  - Number of lanes on major street (23 percent);
  - Other[opportunity for median refuge, crossing distance, or other possible treatment (23 percent)];
  - Crash history (8 percent);
  - Intersection versus midblock (8 percent);
  - Distance to nearest signal (8 percent); and
  - Vehicular gaps available (8 percent).
- **When asked what other factors should be included in the MUTCD, the only factor they listed (and that was not listed as being used in the evaluation of the eight sites—see previous bullet) was sight distance.** There were several comments at individual sites where the adequacy of the available site distance was questionable, especially when on-street parking was present.

Summary

In the 2003 MUTCD, the pedestrian warrant for a traffic control signal considers several factors in determining the need for a signal: pedestrian volume, gaps in vehicular traffic, and walking speed (which may be used to reduce pedestrian volume). Previous studies have documented the difficulty of meeting this warrant at intersections with pedestrian crossing needs. A review of the literature provided insight into the current warrant as well as the signal warranting practices of other countries. In reviewing all traffic control signal warrants, the research team noted several inconsistencies between the pedestrian warrant and vehicle-based warrants. For example, the pedestrian warrant provides a single pedestrian volume criterion, regardless of the major-street vehicle volume being crossed, whereas vehicle-based warrants provide a "sliding scale" where fewer minor-street vehicles are required as the major-street vehicle volume increases. Additionally, vehicle-based warrants permit a vehicle volume reduction to 70 percent when major-street vehicle speeds exceed 40 mph (70 km/h). The research team conducted a workshop to gather engineering judgment about proposed revisions to the pedestrian warrant. In their judgment, most traffic engineers at the workshop believed the following should be considered in a revised pedestrian warrant: width of roadway being crossed, the pedestrian volume, the major-street vehicle volume, and the major-street speed. The research team used these findings to develop the proposed recommendations for a revised pedestrian warrant for traffic control signals (see Appendix B).

CHAPTER 5

Findings From Surveys

This chapter summarizes the findings from surveys used to obtain information on pedestrian treatments as well as the challenges of identifying and providing pedestrian treatments, including traffic control signals. Survey techniques were as follows:

- Focus groups of providers,
- Phone meetings with providers,
- On-site interviews of providers,
- A focus group of bus drivers, and
- On-street interviews of pedestrians.

Appendixes J and K contain details on how each of the surveys was conducted. The observations are summarized below.

Observations From Survey of Providers

Several common themes appeared in the phone conversations, focus groups, and interviews conducted by the research team between December 2002 and June 2003. These themes fall into the following categories and are summarized in the following sections:

- Providing pedestrian crossing treatments,
- Experience with the pedestrian warrant for traffic signals, and
- Transit agency involvement with pedestrian crossings and traffic signals.

Providing Pedestrian Crossing Treatments

The findings on providing pedestrian crossing treatments are summarized as follows:

- **Agencies are installing a wide variety of treatments.** The agencies interviewed have installed a wide variety of pedestrian crossing treatments (in sum total) that range from the inexpensive (e.g., pedestrian crossing flags or in-street pedestrian crossing signs) to just-as-expensive-as-vehicle traffic signals (e.g., midblock pedestrian traffic signals). Each agency by itself has not experimented with such a wide range of crossing treatments, but several agencies have experimented enough to prefer a particular type of treatment to others. City transportation departments were more likely to use innovative or non-standard treatments than state transportation agencies. The state agencies typically favored conservative, traditional approaches that could be more easily defended in tort or liability court cases.
- **There are no universal winners or losers, but treatment effectiveness does vary by street environment.** For specific crossing treatments, no universal "winners" or "losers" emerged from the site visits, focus groups, and interviews. Instead, the persons interviewed indicated that certain crossing treatments could be more effective than others in certain street environments with particular ranges of traffic characteristics. For example, several cities use crossing treatments with steady or flashing red signal displays on high-volume, high-speed roadways to achieve better motorist yielding in this high-risk street environment. These same cities might also use basic crosswalk markings and signs on streets with low to moderate traffic speeds and volumes because motorists are more likely to yield to pedestrians.

Common themes in comments for specific types of treatments follow:

- **Steady or Flashing Red Signal Displays**. Several cities use treatments with red signal displays on high-volume, high-speed arterial streets. For example, the City of Tucson uses a steady and flashing red signal display on pedestrian activation of their HAWK signals. The City of Los Angeles uses midblock pedestrian signals that display a flashing red signal when activated. The Cities of Seattle and Portland use intersection pedestrian signals that, when activated, display a steady red signal on the major street and a Stop sign on the minor street.

- **Flashing Beacons.** Flashing amber beacons are being installed with particular attention to pedestrian expectations. Many of the engineers interviewed noted that once some pedestrians press a pushbutton, they expect all vehicles to yield and thus they may be less cautious crossing the street. Several agencies are using passive detection by sensors instead of manual pushbuttons to detect waiting or crossing pedestrians, but this passive detection requires more resources for installation and maintenance. Also, most cities prefer manual pushbutton activation of flashing amber beacons to continuously flashing beacons, which traffic officials think eventually lose effectiveness.
- **In-Roadway Warning Lights.** Many cities have installed in-roadway warning lights, but several cities were taking a cautious approach. Several agencies were concerned about the visibility of in-roadway warning lights (absent any additional overhead or side-mounted flashing beacons) in direct sunlight or in queued traffic. A few cities also mentioned concerns about pedestrian expectations with pedestrian activation or detection problems with passive detection sensors. A few cities also mentioned that they did not want to jump on the "in-roadway lights bandwagon" and that these devices might be an engineering fad that slowly falls out of favor after more extensive installations.
- **Median Refuge Islands.** Nearly all cities interviewed indicated that, where possible to install, a median refuge island was almost always considered, either alone or in conjunction with other treatments. Even the state DOTs, which seemed to favor more traditional approaches, considered median refuge islands an effective treatment to be used wherever possible. One state transportation representative did mention others' concerns about the crash-worthiness of curbed median refuge islands on high-speed streets.
- **Advanced Stop/Yield Lines.** Several cities interviewed are using advanced stop or yield lines (i.e., transverse triangles), typically placed between 30 and 40 ft (9 and 12 m) in advance of the crosswalk markings. The advanced stop/yield lines were held in similar regard as median refuge islands, in that they were being used as a standard design element with crosswalk markings alone or with other more substantial crossing treatments.
- **Crosswalk Markings.** Numerous cities indicated that they use the 2002 FHWA guidelines on crosswalk markings (*50*) to find out where to mark crosswalks as well as where to provide more substantial pedestrian crossing treatments. Numerous cities also mentioned that they use much greater care in selectively marking crosswalks than they have in the past. A few engineers interviewed still interpret these recommendations as supporting a "mark versus do not mark" decision rather than a "mark versus more substantial treatment" decision.
- **In-Street Pedestrian Crossing Signs.** Interest in in-street pedestrian crossing signs has been growing. They are viewed as an appropriate treatment for lower-speed (30 mph [48 km/h] or less) roadways. The signs are used to remind drivers of their legal obligation with respect to pedestrians in crosswalks.
- **Flags.** Pedestrian crossing flags are also viewed as an appropriate treatment for lower-speed (35 mph [55 km/h] or less) roadways. Salt Lake City, Utah, has 120 locations with flags, and Kirkland, Washington, has several installations. Some of the other communities interviewed question the flags' effectiveness and replacement efforts and costs. The flags are to be picked up by a pedestrian and used to indicate the desire to cross the street. The pedestrian is to place the flag in the holder when done crossing the roadway; however, sometimes flags are not returned. Cities with experience observe that the rate of disappearance decreases after the treatment has been in place for a while. Salt Lake City requires that neighborhood associations or businesses "adopt" the crossing and maintain the supply of crossing flags.

Experience with the Pedestrian Warrant for Traffic Signals

Comments on experiences with the pedestrian warrants follow.

- **The pedestrian volumes in the MUTCD warrant are too high to meet.** The engineers who expressed concern about the MUTCD pedestrian warrant unanimously agreed that the required pedestrian volumes were too high to adequately address many pedestrian crossing issues in their jurisdiction. To address their pedestrian issues, many engineers either installed crossing treatments that are less restrictive than traffic signals, modified the existing MUTCD pedestrian warrant, or used a supplementary engineering analysis to justify a traffic signal installation.
- **Cities' modifications to the existing MUTCD warrant might have merit.** Some of the agencies developed new criteria for pedestrian signals to better address pedestrian accommodation issues in their respective jurisdictions. For example, Redmond recently adopted an approach that includes pedestrian volumes that are 80 percent of the values included in the MUTCD. Other cities incorporate reduction factors for different street environments or different pedestrian populations (e.g., school children, elderly pedestrians, and those with physical disabilities) and consider project demand or project transit ridership in their warrant analyses.

- **Useful criteria for other pedestrian crossing treatments exist.** In addition to modifying the existing pedestrian warrant for traffic signals, several cities have developed installation criteria for other pedestrian crossing treatments such as in-roadway warning lights or flashing beacons.

Transit Agency Involvement with Pedestrian Crossings and Traffic Signals

Transit agencies are active in providing safe crossings. Following is a summary of transit agency involvement:

- **The level of coordination varies between transit staff and city engineers.** The level of coordination between transit agency staff and city engineering staff varies from close collaboration to casual communication. The level of coordination appears to depend on the existing institutional relationships. In areas with the greatest collaboration, city engineering and transit agency staff worked closely in locating transit stops/stations and installing pedestrian crossing accommodation. In other areas, the relationship was less collaborative and information sharing may have been on a "need-to-know" basis.
- **Some transit agencies address pedestrian issues.** Some transit agencies are attempting to address pedestrian issues through stop location and design. For example, one transit agency was re-evaluating stop locations along several major arterial streets and consolidating some stops closer to intersections or preferred pedestrian crossings. The same transit agency was also considering shifting some bus service to parallel streets to avoid the harsh pedestrian crossing environments of high-speed, high-volume highways (although such shifts to lower-speed streets would affect transit mobility). Several transit agencies (or the respective cities) provide extra lighting at busy evening and nighttime stops. Along some routes with widely spaced signals, though, transit agencies have no options other than placing stops at unsignalized locations.
- **Several cities consider transit activity in pedestrian improvements.** Several cities are considering transit stops in pedestrian improvements. For example, city staff may obtain transit boardings and alightings at certain locations to have a better sense of total pedestrian activity. Or, when considering certain roadway changes or improvements, city staff may contact the transit agency to discuss any similar transit improvements. Many of the city staff interviewed understand the importance of the pedestrian environment in transit mode choices.
- **Transit agencies provide funds.** Several transit agencies commented that they have and will continue to contribute funds toward pedestrian treatments. When appropriate, they will also install bus shelters or other pedestrian amenities (e.g., lighting) to encourage the consolidation of pedestrians into a preferred crossing location.

On-Street Pedestrian Surveys

The goal of the on-street pedestrian survey was to obtain the perspectives of pedestrians on their experiences and needs at unsignalized pedestrian crossing locations. Appendix K contains details on the methodology used and findings from the surveys. The methodology and findings are summarized below.

Seven sites with five different treatments were ultimately selected for study. The sites were selected on the basis of pedestrian traffic volumes, pedestrian crossing treatment, and roadway characteristics. The selected sites reflected numerous crossing treatments in order to obtain greater perspective on pedestrian experiences. The treatments consisted of two marked crosswalk treatments, an in-roadway flashing light treatment, a HAWK treatment, two split midblock signal treatments (locally called a "pelican"), and a countdown pedestrian signal treatment at a signalized intersection. The data collection sites were in urban areas with high traffic volumes. Table 13 lists the selected sites and where they were and summarizes key characteristics of the site.

Table 13. Treatment characteristics.

Site #	Site Location	Pedestrian Treatment	Number of Lanes	Median Present	Distance to Nearest Signalized Intersection
1	Austin, TX	Marked Crosswalk	Four	Two-Way Left-Turn Lane	200 ft (61 m)
2	Tucson, AZ	Marked Crosswalk	Six	Raised	600 ft (183 m)
3	Austin, TX	In-Roadway Warning Lights	Four	Raised	550 ft (168 m)
4	Tucson, AZ	HAWK	Four	Raised	1,000 ft (305 m)
5	Tucson, AZ	Split Midblock Signal	Six	Raised	3,200 ft (975 m)
6	Tucson, AZ	Split Midblock Signal	Six	Raised	950 ft (290 m)
7	Lauderdale by the Sea, FL	Countdown Display at Signalized Intersection	Two and Four	Raised	Not Applicable

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Survey Design

The on-street pedestrian survey had three sections. The first section was to obtain pedestrians' opinions of the street crossing treatment. The second section asked general questions for demographic purposes only. The questions used in Sections 1 and 2 are listed in Table 14. The third section consisted of recording several demographic characteristics that were observed for comparison purposes only. In addition, researchers observed the crossing behavior of the pedestrians at the study location to record if they used the designated crossing, jaywalked, crossed at a nearby intersection, or did something else.

A tally was kept of those pedestrians refusing to participate in the survey and why. Reasons given for refusing the survey included that they did not speak English, were in a hurry, or simply preferred not to participate. This information was recorded to determine the level of participation at each location.

Survey Protocol

The survey was administered at the selected locations where pedestrians could be approached after they crossed at the study site. The potential participants were approached and asked if they would be willing to complete a survey about pedestrian crossings that would take about 5 minutes. The surveyor would read the questions to participants and record his or her responses. On completing the survey, the researcher would record the observational data on the survey form. At each site, the researchers interviewed at least 40 pedestrians to obtain their opinions on the pedestrian crossing treatment.

Conclusions for On-Street Surveys

Appendix L contains information on the findings for each individual site. Survey conclusions follow.

When determining the amount of traffic control to be used at a pedestrian crossing location, many factors should be considered. Those that affect the perception of pedestrians most are

- Traffic volume,
- Turning traffic,
- Presence of pedestrians with handicaps,
- Traffic speed, and
- The availability of an alternate crossing.

This study revealed that, as the control at a pedestrian crossing increases through the addition of signs, flashing lights, and/or signals, the pedestrians' perception of safety also increases. This trend is illustrated in Figure 11 where the average pedestrian safety ratings for each site are plotted. The ratings were based on a scale where 1 indicates very safe and 5 indicates unsafe. Figure 11 also shows the sites as they progress from least amount of control at the left to most amount of control at the right.

The one abnormality in this trend is that the signalized intersection (Site 7) is considered either to be equally safe or less safe than the split midblock signal treatment (Sites 5 and 6). Researchers believe that this variance is because pedestrians crossing at a major signalized intersection deal with a larger number of turning vehicles, which diminishes their perceptions of safety.

Table 14. Survey questions.

Question Number	Question
	SECTION 1
1	On a scale of 1 to 5 (with 1 being very safe and 5 not safe) how safe did you feel crossing this street?
2	Is there anything at this street crossing that was confusing or that you had a hard time understanding? If yes, explain.
3	What is the maximum amount of time a person should have to wait to cross this street? <30 s, <1 minute, <2 minutes, <3 minutes
4	Do you think this (name of crosswalk treatment) is safe and effective? Why or why not?
5	Is there any thing else that could be added to improve the safety of this street crossing? If yes, explain.
6	(If at an uncontrolled crossing) If this crossing was not here, would you walk to that next intersection (point to intersection of interest)? Why or why not?
	SECTION 2
7	Did your trip today start with a bus ride, car, or walking?
8	In a typical week, how many times do you cross the street at this location?
9	How many streets do you cross in a typical day? 1 to 5, 6 to 10, 11 to 15, 16 to 20
10	Do you have a current driver's license? Yes No
11	Do you consider yourself to be visually disabled/impaired? Yes No
12	Is your age category between: 21-40 41-55 56-64 65+

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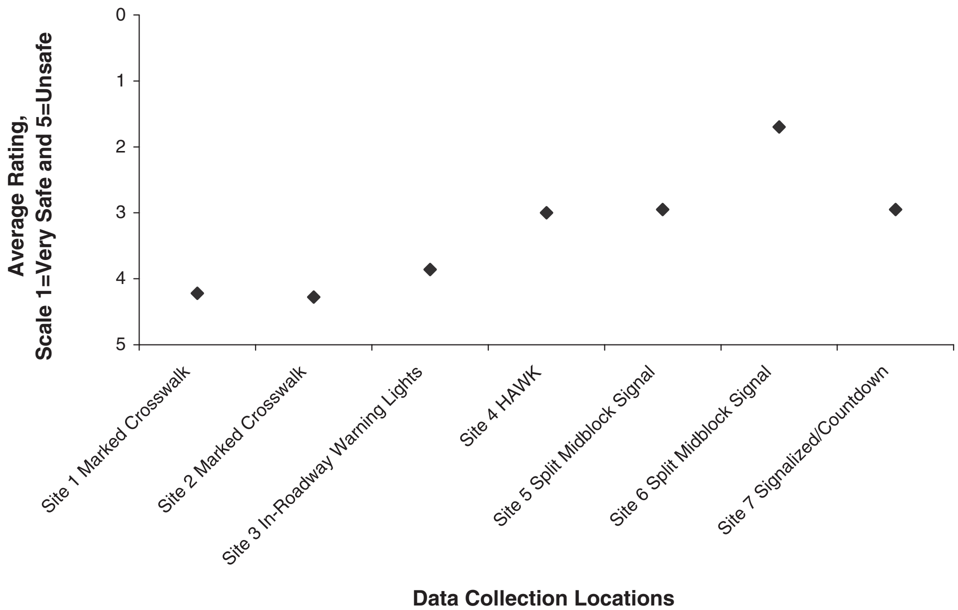

Figure 11. Average pedestrian safety ratings.

The unpredictability of drivers remains the number one concern to pedestrians, no matter the pedestrian treatment used. Even at highly controlled crossings where all traffic is required to stop, determining whether a vehicle will obey the signal was one of the major concerns of the pedestrians surveyed.

Finally, pedestrians can be greatly influenced by their own abilities. At the two sites with the split midblock signal treatment (Sites 5 and 6), perceptions were greatly altered depending on the pedestrian population. At a location where a greater number of people who are elderly or have disabilities will be crossing, the extended median was viewed favorably. However, at the location without this type of pedestrian traffic, the jog in the pedestrian path is considered a delay and therefore not an effective crossing design.

Summary

The research team conducted several interviews and surveys in early phases of the project to gather information about pedestrian crossing treatments, use of the pedestrian warrant, and pedestrian concerns in general.

Interviews with traffic engineers revealed the use of several different crossing treatments, most of which were evaluated in this project. Most engineers recognized that treatment effectiveness varied by street type and traffic conditions. Many engineers expressed difficulty in using the pedestrian traffic signal warrant to address pedestrian crossing problems. Some engineers had developed a modified pedestrian signal warrant process that was less restrictive than the MUTCD warrant.

Interviews with transit agency staff revealed awareness that pedestrian crossings were an issue at transit stops. Several transit agencies coordinated with city and state engineers in locating transit stops and improving pedestrian crossings.

Curbside interviews with pedestrians indicated the following most common pedestrian concerns: traffic volume (particularly turning traffic), vehicle speeds, and unpredictability of motorists (i.e., whether they will stop at marked crosswalks). The curbside surveys also indicated that pedestrians typically feel safer with greater levels of vehicle control (i.e., traffic signals or red signal/beacon devices).

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CHAPTER 6

Field Studies

This chapter summarizes the field data collection approaches used in this project to evaluate pedestrian crossing treatments. Details on the study sites as well as the data collection techniques are provided below.

Background

A field study approach was developed to provide insight into the actual behavior of motorists and pedestrians at locations with existing pedestrian crossing treatments. The specific measures of effectiveness (MOEs) used for the pedestrian crossing evaluations are listed in Table 15. Also, the research team collected data on site conditions at existing crossing treatment locations, which were used to help explain the variation in MOE results for similar treatments at different locations. Essentially, the team conducted observational and operational studies at existing crossing treatments with special consideration given to site conditions that ultimately influenced the effectiveness of crossing treatments.

The primary MOEs focused on motorist and pedestrian behavior, conflicts, and delays at existing crossing treatment locations. The research team believed that this combination of behavioral and operational data analysis provided the best insight into the effectiveness of pedestrian crossing treatments. Table 15 summarizes the MOEs along with the method of calculation or the categories used to classify them.

In addition to these MOEs, other crossing characteristics were desired in order to gain a thorough understanding of pedestrian movements at each site. Some of these characteristics included the gender of the pedestrian, the direction of the crossing movement, and the number of vehicles that did not stop when the treatment was activated.

Site Selection

The initial goal for the project was to collect data at 40 sites. Potential sites were identified during the project's Phase I travels and contacts with cities, states, and transit agencies. States in this initial list were Texas, Utah, Washington, Oregon, California, and Arizona. Comprehensive evaluation data were collected at 40 sites, and video for an additional two sites was provided to the research team for analysis. Two of the three additional sites were in Maryland, while the remaining site was a midblock crosswalk in Arizona that had been selected for data collection by the research team. Therefore, 42 unique locations are represented in the evaluation dataset.

The sites were selected to represent various treatment types and site conditions. Specific site selection was based on several factors so that the research team could obtain data across a representative range of treatment types, street environments, and traffic conditions. The primary factors were as follows:

- Proximity to transit stop – sample of sites near or at a transit stop,
- Roadway type – moderate to high traffic volumes,
- Proximity to driveways – locations where turning traffic conflicts from nearby driveways are nominal,
- Area type – suburban and urban, and
- Pedestrian age and ability – sample of sites with a range of pedestrian ages represented including the elderly and pedestrians with disabilities.

Study Sites

In total, 42 study sites were selected in seven different states (see Table 16). The study sites were chosen in an effort to distribute the different types of crossing treatments in certain regions, such that the data for a particular treatment is not collected from a single city. This could not be avoided for two treatments (i.e., HAWK and in-street crossing sign) were each only installed in a single city. The sites were chosen to focus on arterial streets, with a range of operational and design

Table 15. Summary of pedestrian crossing treatment measures of effectiveness.

MOE	Description	Categories or Method of Calculation
Pedestrian visual search	Percent of crossing events in which pedestrians use proper visual search	1. Looked in both directions 2. Looked in only one direction 3. Did not look in either direction
Pedestrian crosswalk compliance	Percent of crossing events in which pedestrians cross within 10 ft (3 m) of marked crosswalk	1. Crossed within 10 ft (3 m) of crosswalk 2. Crossed between 10 and 50 ft (3 and 15 m) from crosswalk 3. Crossed greater than 50 ft (15 m) from crosswalk
Pedestrian activation	Percent of crossing events in which pedestrians activate treatment (where applicable)	1. Activated treatment and waited for proper time to cross 2. Activated treatment but did not wait 3. Did not activate treatment 4. Treatment malfunctioned (no activation)
Pedestrian-vehicle conflicts	Percent of crossing events having a pedestrian-vehicle conflict	1. Conflict with first direction of major street vehicular traffic 2. Conflict with second direction of major street vehicular traffic 3. Conflict with left-turning side street traffic 4. Conflict with right-turning side street traffic
Pedestrian delay	Seconds of delay per pedestrian while waiting to cross	Difference in time between these two events: 1. The pedestrian approached within 3 ft (0.9 m) of the crossing and indicated intent to cross the street. 2. The pedestrian began to cross the street.
Pedestrian walking speed	Average walking speed (ft/s) of pedestrian groups	1. Elderly and/or with physical disabilities 2. School children (ages 0-12) 3. Teenagers (ages 13-18) 4. Young adult (ages 19-30) 5. Middle aged (ages 31-60) 6. Older (age above 60 but not in Group #1)
Motorist compliance	Percent of motorists yielding or stopping for pedestrians	Number of cars that stopped for (or yielded to) the staged pedestrian divided by the number of cars that should have stopped

characteristics (e.g., number of lanes, presence of median refuge island, and speed limit). Although not by design, 40 of the 42 study sites were in the western United States. However, the sites still included a wide range of climate and urban design features that were important to represent (e.g., snowfall, cold winters, pedestrian-friendly versus less-than-friendly street design, and aggressive drivers).

Descriptions of Crossing Treatments

The research team categorized the crossing treatments into three basic types according to function and design:

- Red signal or beacon – devices that display a circular red indication to motorists at the pedestrian crossing location. Examples (see Figure 12) include a midblock traffic signal, half signal, or HAWK signal beacon.
- Active when present – devices that display a warning only when pedestrians are present or crossing the street. Examples (see Figure 13) include flashing amber beacons (both push-button and passive detection) and pedestrian crossing flags.
- Enhanced and/or high visibility – devices and design treatments that enhance both the ability of pedestrians to cross the street and the visibility of the crossing location and pedestrians waiting to cross. Warning signs and markings in this category are present at the crossing location at all times. Examples (see Figure 14) include in-street pedestrian crossing signs, high-visibility signs and markings, and median refuge islands.

The treatment abbreviations as shown in subsequent tables and figures are as follows:

- Half signals (Half);
- HAWK signal beacon (HAWK);
- Midblock pedestrian signal (Msig);
- Smart pedestrian warning, where an overhead pedestrian sign and two yellow flashing beacons are passively activated by an approaching pedestrian (OfPa),
- Overhead flashing beacons, where an overhead pedestrian sign and two yellow flashing beacons are activated when a button is pushed by the pedestrian (OfPb);
- Pedestrian crossing flags (Flag);
- High-visibility markings and signs (HiVi);
- In-street pedestrian crossing sign (InSt); and
- Pedestrian median refuge island (Refu).

Figure 15 shows the number of sites in the seven states represented in the study. Table 17 lists the 42 sites included in the study along with their characteristics.

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Table 16. Summary of study sites.

City	Crossing Treatment	Number of Study Sites	Range in Through Lanes	Range in Speed Limit (mph)
Tucson, AZ	HAWK signal beacon	5	4 to 6	30 to 40
	High-visibility markings and signs	2	4	25 to 35
Los Angeles, CA	Overhead flashing beacon (passive)	4	2 to 4	30 to 35
	Midblock signal	4	4 to 5	25 to 35
Santa Monica, CA	Median refuge island, high-visibility signs	2	4	30
Capitol Heights, MD	Overhead flashing beacon (continuous)	1	6	35
Towson, MD	Overhead flashing beacon (pushbutton)	1	4	35
Portland, OR	Half signal	3	4	35
	Median refuge island, high-visibility signs	3	2 to 4	25 to 35
Austin, TX	High-visibility signs and markings	1	4	35
College Station, TX	Median refuge island, high-visibility signs	1	4	35
Salt Lake City, UT	Overhead flashing beacon (pushbutton)	3	4	30 to 35
	Pedestrian flags	3	4 to 6	30 to 35
Kirkland, WA	Pedestrian flags	3	2 to 4	25 to 35
Redmond, WA	In-street crossing sign	3	2 to 3	25 to 30
Seattle, WA	Half signal	3	3 to 4	35

Protocol for Data Collection

The data collection and analysis protocol for evaluating the effectiveness of treatments used two approaches for collecting the data:

- General population pedestrians–use on-site and videotaped observations to record various pedestrian behavior and operational characteristics, and
- Staged pedestrians–use staged pedestrians to measure motorist compliance at existing pedestrian crossing treatments.

General Population

Observation studies were used to record numerous pedestrian behaviors and operational characteristics. A video recording was made of the crossing to permit review and data reduction after the actual crossing event occurred. It was necessary to observe actual pedestrian behavior (rather than simply using staged pedestrians) to measure a part of the crossing treatment's effectiveness.

In general, the following protocol was used in the observation studies:

- A minimum of 100 pedestrian crossing events or 4 hours of data (whichever occurred first) were recorded at each location, where each crossing event consisted of one or more pedestrians crossing the entire width of the street.
- Two members of the project team were positioned at inconspicuous locations near the pedestrian crossing to make anecdotal notes of the crossing events. These anecdotal notes did not include quantitative data on the MOEs in Table 15 but instead focused on qualitative observations about vehicle and motorist behavior.
- The on-site field observers counted the number of pedestrian crossing events as they occurred to ensure that the minimum sample size of 100 crossing events was achieved as time allowed.

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Midblock Traffic Signal

Characteristics

- A midblock signal is a standard traffic signal that is not located at an intersecting cross street.
- The pedestrian phase for a midblock signal is typically activated by a pushbutton and can consist of a steady red indication or a sequence of steady red and then flashing red indications for drivers.
- A midblock signal typically dwells in steady green (or green arrow) for vehicles.
- A supplemental sign is typically used to indicate the signal is for pedestrians.
- The signal is subject to requirements specified in the MUTCD.

Half signal (Intersection Pedestrian Signal)

Characteristics

- A half signal is a standard traffic signal (with red, yellow, and green indications) for the major road. When located at an intersection, the minor cross street has Stop sign control.
- The pedestrian phase for a half signal is typically activated by a pushbutton and consists of a steady red indication.
- In the United States, most installed half signals dwell in steady green for vehicles, whereas most half signals in British Columbia dwell in flashing green.
- This is an experimental traffic control device not currently included in the MUTCD.

HAWK Signal Beacon

Characteristics

- A HAWK signal beacon resembles an emergency vehicle beacon and only provides yellow and red indications for drivers. Pedestrians see standard pedestrian control features.
- The pedestrian phase for a HAWK signal beacon is typically activated by a pushbutton. Drivers see a sequence of flashing yellow, steady yellow, steady red, and flashing red indications.
- The HAWK signal beacon, used exclusively in Tucson and Pima County, Arizona, dwells in a dark mode for vehicles.
- This is an experimental traffic control device not currently included in the MUTCD.

Figure 12. Red signal or beacon devices.

- The observers and the video recording devices were positioned to be, as much as possible, inconspicuous to both the pedestrians and motorists.

Staged Pedestrian Tests

Staged pedestrian tests were used to measure motorist compliance at existing pedestrian crossing treatments. Staged pedestrians were used in the belief that consistent presentation of a pedestrian intent to cross was critical for comparing motorist compliance results from different locations or areas of the country; in other words, pedestrian positioning, stance, and aggressiveness affect a motorist's decision to stop or yield at a pedestrian crossing. For example, motorists are less likely to stop or yield when pedestrians stand several feet behind the curb line (e.g., the pedestrian may appear as though they are waiting instead of intending to cross).

The following protocols were used in the staged pedestrian tests:

- A minimum of 40 staged crossings (i.e., 20 crossings in each direction) were performed at each location.
- The staged pedestrian was a male dressed in blue jeans and a neutral-colored shirt (e.g., gray, blue, tan, or white).

Flashing Amber Beacons

Characteristics

- Overhead flashing amber beacons are mounted on mast arms that extend over the roadway at or in advance of the crossing location. Flashing amber beacons can also be mounted on signposts at the roadside.
- The flashing beacons can be activated by either a pushbutton or a passive detection technology, such as bollards, video, or microwave sensors.
- Continuously flashing beacons are not included in this category; they are included in the enhanced and/or high-visibility category.
- This traffic control device is subject to requirements specified in the MUTCD.

Pedestrian Crossing Flags

Characteristics

- Pedestrian crossing flags are square flags (of various colors, typically orange, yellow, or fluorescent yellow-green) mounted to a stick that is held by pedestrians waiting to cross or while crossing the street.
- The flags are typically stored in sign-mounted holders on both sides of the street at crossing locations.
- This is an experimental device not currently included in the MUTCD.

Figure 13. "Active When Present" devices.

- The staged pedestrian approached the crossing, activated the crossing treatment (where applicable), and stood facing oncoming traffic within 1 ft (0.3 m) of the curb line (even when parking or bike lanes are present). Where no curb was present, the staged pedestrian stood within 1 ft (0.3 m) of the outside edge of the curb lane.
- The staged pedestrian could approach the crossing at any time when vehicles were within sight distance of the crossing. Vehicles that were too close to comfortably stop—estimated as being inside the stopping sight distance per AASHTO *Green Book*—were not counted in the test (*56*).
- Staged pedestrians avoided attempting to cross while other pedestrians were attempting to cross.
- Motorists who did not stop were counted as not complying. Motorists who slowed down without passing through the crosswalk to permit the staged pedestrian to safely cross were considered yielding vehicles.
- For multi-lane approaches, the staged pedestrian took one or two steps into the street if the curb lane motorist stopped/yielded but a motorist in the inside lane was still approaching.
- For divided roadways with a median refuge island, the staged pedestrian paused as necessary within 1 ft (0.3 m) of the island curb line (or inside lane line) before crossing the second direction of traffic.
- Staged pedestrians aborted the crossing attempt after 1 minute if no vehicles stopped or yielded.
- A second research team member and a video recording device were always present but inconspicuous to motorists during the staged pedestrian tests.

Collection Approaches

To obtain the general population and staged pedestrian data, the following data collection approaches were used:

- Videocameras were used to provide a permanent record of pedestrian and motorist behavior.
- Palmtop computers were used on site to record certain aspects of pedestrian and motorist behavior.
- Site condition sheets were used to document geometric characteristics of each site.

The specific protocol for each of these activities is described in more detail in the following sections.

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In-Street Pedestrian Crossing Signs

R1-6 **R1-6a**

Characteristics

- In-street crossing signs are regulatory signs placed in the street (on lane edge lines and road centerlines, or in medians) to remind road users of laws regarding right-of-way at an unsignalized pedestrian crossing.
- This traffic control device is subject to requirements specified in the MUTCD.

High-Visibility Signs and Markings

Characteristics

- High-visibility signs and markings are warning devices placed at or in advance of the pedestrian crossing.
- These include fluorescent-yellow-green pedestrian crossing signs, other pedestrian crossing signs, high-visibility crosswalk markings, and other devices that attempt to draw attention to the pedestrian crossing.
- Many of these high-visibility signs and markings are included in the MUTCD and are subject to requirements specified in the MUTCD.

Median Refuge Islands

Characteristics

- Median refuge islands are a design treatment that permits pedestrians to cross one direction of street traffic at a time.
- Median refuge islands are typically raised above the roadway surface with an accessible pedestrian path, typically offset to direct the view of crossing pedestrians at the second direction of street traffic.
- Two-way left-turn lanes and other median treatments that vehicles routinely enter are not considered appropriate refuge for pedestrians.
- Curb extensions, roadway narrowing, raised crosswalks, and other design treatments or traffic-calming elements can also be used to improve the safety of unsignalized pedestrian crossings.

Figure 14. "Enhanced and/or High-Visibility" devices.

Figure 15. Location and number of study sites.

Video Data Collection Approach

Originally the research team intended to collect the necessary data by videotaping the crossing movements at the various study sites. Using video data would provide a record of the events that took place during the study period. In the data reduction process, it was possible to review these events numerous times to consistently interpret and record needed information about pedestrian crossing events.

The video recording of pedestrian activities primarily used one of TTI's two camera trailers, which can raise a camera 30 ft (9 m) in the air to record a bird's-eye view of the study area. The video trailer is normally outfitted with a single videocassette recorder (VCR) and a monitor, along with a hydraulic

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Table 17. Study sites and their characteristics.

Site Number	Treatment	Speed Limit	Lanes	Median Width (ft)	Curb to Curb (ft)	Parking Lane	Bicycle Lane	Curb Extension	Near Sidewalk	Far Sidewalk	Distance to Transit (ft)	Distance to Signal (ft)	Midblock Crossing
AZ-TU-1	Hawk	40	6	20.00	100.17	N	N	N	Y	Y	45	1600	N
AZ-TU-2	Hawk	35	6	20.00	103.50	N	Y	N	Y	Y	105	1255	N
AZ-TU-3	Hawk	35	6	20.00	100.50	N	Y	N	Y	Y	125	1225	N
AZ-TU-4	Hawk	35	4	13.00	72.00	N	Y	N	Y	Y	0	975	N
AZ-TU-5	Hawk	35	4	12.00	63.75	N	N	N	Y	N	108	1274	N
AZ-TU-6	HiVi	35	4	20.00	72.50	N	N	N	Y	Y	123	1280	N
AZ-TU-7	HiVi	25	4	12.00	57.33	N	N	N	Y	Y	69	197	Y
CA-LA-1	OfPa	35	4	11.00	75.00	Y	N	N	Y	Y	20	562	N
CA-LA-2	OfPa	35	4	11.00	83.00	Y	N	N	Y	Y	325	684	N
CA-LA-3	OfPa	30	2	12.50	60.50	Y	N	N	Y	Y	285	350	N
CA-LA-4	Msig	25	4	10.00	70.00	Y	N	N	Y	Y	250	320	Y
CA-LA-5	Msig	25	5	0.00	57.00	Y	N	N	Y	Y	90	295	Y
CA-LA-6	Msig	35	4	0.00	60.00	Y	N	Y	Y	Y	200	360	Y
CA-LA-7	Msig	NP	4	10.00	80.00	N	N	N	Y	Y	60	850	Y
CA-LA-8	OfPa	35	4	10.00	60.00	N	N	N	Y	Y	55	720	N
CA-SM-2	Refu	30	4	6.00	66.00	Y	N	N	Y	Y	>2600	420	N
CA-SM-3	Refu	30	4	16.00	76.00	Y	N	N	Y	Y	20	370	N
MD-P1	Refu	35	6	22.00	92.00	N	N	N	Y	Y	0	500	Y
MD-TO-1	OfPb	35	4	0.00	46.00	N	N	N	Y	Y	400	950	N
OR-PO-1	Refu	35	4	8.50	60.67	N	Y	Y	Y	Y	188	675	N
OR-PO-2	Half	35	4	12.00	77.00	Y	Y	N	Y	Y	153	500	N
OR-PO-3	Half	35	4	0.00	50.00	N	N	N	Y	Y	0	535	N
OR-PO-4	Half	35	4	0.00	51.00	Y	N	N	Y	Y	0	780	N
OR-PO-5	Refu	25	2	10.00	44.00	N	N	Y	Y	Y	0	785	N
OR-PO-6	Refu	35	4	9.00	75.50	Y	Y	Y	Y	Y	110	1000	N
TX-AU-1	HiVi	35	4	10.00	50.00	N	N	N	Y	Y	185	190	N
TX-CS-1	Refu	35	4	10.00	54.50	N	N	N	Y	Y	1056	530	Y
UT-SL-1	Flag	30	6	5.50	96.83	Y	N	Y	Y	Y	0	242	N
UT-SL-2	OfPb	30	4	0.00	54.00	N	N	N	Y	Y	208	360	N
UT-SL-3	OfPb	35	4	0.00	70.00	N	N	N	Y	Y	2600	800	N
UT-SL-4	OfPb	35	4	0.00	56.75	N	N	N	Y	Y	0	1848	N
UT-SL-5	Flag	35	4	9.08	68.00	N	N	N	Y	Y	71.5	1320	N
UT-SL-6	Flag	30	4	12.33	83.33	Y	N	Y	Y	Y	600	600	N
WA-KI-1	Flag	35	2	11.42	57.92	Y	Y	N	Y	Y	50	2640	N
WA-KI-2	Flag	30	4	0.00	60.00	Y	N	Y	Y	Y	2600	215	N
WA-KI-3	Flag	25	2	0.00	45.00	Y	N	Y	Y	Y	97	473	N
WA-RD-1	InSt	25	2	0.00	38.25	N	N	N	Y	N	>2600	2700	Y
WA-RD-2	InSt	30	3	8.00	49.50	N	N	N	Y	N	2600	439	N
WA-RD-3	InSt	30	2	10.50	43.50	N	N	N	Y	Y	234	345	N
WA-SE-1	Half	35	4	0.00	54.50	Y	N	N	Y	Y	61	447	N
WA-SE-2	Half	NP	2	12.00	54.00	Y	Y	N	Y	Y	104	534	N
WA-SE-3	Half	35	4	0.00	42.00	N	N	N	Y	Y	123	291	N

lift system on the roof of the trailer that raises an attached videocamera. For this project, a second VCR and camera were added to the trailer. One camera provided a wide-angle view of the area around the crossing under observation, while the second camera was zoomed in for a more detailed view of the crossing itself and the pedestrians using the crossing. The entire outfit in the trailer was powered by a portable generator or, if available, a nearby fixed electrical outlet.

A drawback of the video trailer was that it required the trailer to be driven to the study sites, and a place to park the trailer at each site had to be found. An issue at each study site was whether there would need to be a trade-off between the necessary viewing angle of the trailer and the need to be relatively inconspicuous. At selected sites, it was not possible to position the trailer in an inconspicuous location and still obtain an unobstructed view of the entire crossing and approaches. In these instances, supplemental battery-powered camcorders were used in conjunction with the video trailer to complete the necessary visual record.

Observation Data Collection Approach

Despite the advantages of video data collection, the use of only video data would have had some significant drawbacks. First, the amount of time necessary to pull all pedestrian and motorist characteristics from the video for each crossing would be immense. Although rewinding and fast-forwarding the video to review specific characteristics of crossing events would be possible, this would have to be done multiple times for each crossing. Second, the images obtained from the video

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Figure 16. Video record of pedestrians crossing in twilight.

did not always provide the detail and resolution necessary to record certain characteristics. Gathering characteristics such as pedestrian age and gender would not be possible if video was the only data available for each crossing. Figures 16 and 17 illustrate video records with insufficient resolution; the crossing pedestrians are circled for emphasis.

Because of these limitations, it was decided that members of the research team should make personal visual observations on site during the intervals of video data collection. The first approach was to record these observations on a printed data sheet. However, initial tests revealed that, especially in cases of high pedestrian volumes, it was extremely difficult to write down the necessary information in a timely manner and still ensure the accuracy of the data.

The next attempted method of collecting observation data was a personal digital assistant (PDA), also known as a palmtop computer. A program was written for the PDA to collect information on various types of pedestrian crossing characteristics and save them to a database. Through a series of drop-down menus and radio buttons, the observation data could be collected quickly and accurately.

Figure 17. Video record of pedestrian partially obscured by background clutter.

Initial tests of the PDA revealed that the PDA was more efficient, so much so that more items were added to the PDA program. One of the screens of the PDA program is shown in Figure 18. This screen was used to collect specific information on the pedestrian crossing. At the top of the screen, the observer would note the type of pedestrian crossing using the radio buttons at the top. In the two columns below, the observer could then record 10 characteristics about the pedestrian and the crossing maneuver: crossing direction, lighting conditions, gender, age, activation conditions, looking behavior, start-of-crossing behavior, crosswalk compliance, the number of vehicles not stopping, and the distance between the pedestrian and the nearest vehicle that did stop or yield. Finally, there was a button for the observer to indicate whether the record was complete with all the items for the crossing recorded. Occasionally, especially during periods of high pedestrian traffic, the observer might be unable to record one or more items; noting "Incomplete" would be a signal to look for the unrecorded items on the video during the reduction process. Tapping the "Save" button would save the information for that crossing record into the database; tapping the "Back" button would return the observer to the previous screen.

The primary benefit of using the PDA to collect this portion of the data was that a large amount of data could be stored and easily downloaded later. The information gathered on each screen was saved to a database file for more detailed calculations and analysis. The downloaded data was already formatted and ready for integration with the data collected from the video, which further improved the efficiency of the reduction process.

Both video data and observation data were post-processed manually to determine pedestrian volumes, pedestrian gap acceptance levels, pedestrian delay threshold levels, and behavior as pedestrians wait for an adequately sized gap.

Site Characteristics Data Collection Approach

In addition to motorist and pedestrian behavior, the research team also collected data on the characteristics of the study site that included roadway, overall location, and pedestrian characteristics. These site characteristics data would be used for explaining the variation in treatment effectiveness at different locations (e.g., were posted speed limit and average daily traffic volume strong predictors of treatment effectiveness within a particular group of treatments?). Most of these

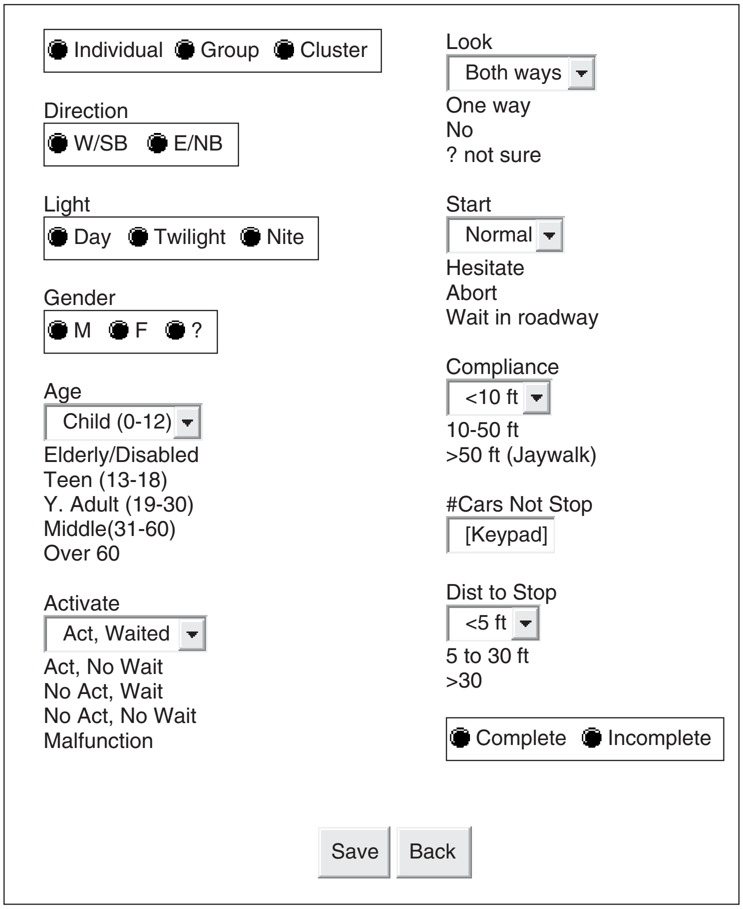

Figure 18. Screen #3 of PDA program.

site characteristics were recorded by hand on a pre-printed data sheet and supplemented by a hand-drawn sketch of the geometric configuration of the site. The sketch contained key geometric dimensions of the study site, which were recorded by hand measurements, as shown in Figure 19. The remaining site characteristics were collected from the video.

Finally, observers also took multiple pictures of each site using a digital camera. These pictures illustrated the various approaches to each crosswalk, relevant traffic control devices, other conditions at the site, and any unusual characteristics that might have been present. The pictures supplemented the sketch and the recorded video for use in reviewing characteristics of each site.

Data Reduction

Both video and palmtop computer data were post-processed manually to determine pedestrian behavior at each site. PDA data were downloaded and stored in a database file at the conclusion of the study period for each site. These database files were converted to spreadsheet files to expedite calculations for various emphases in the data reduction: motorist behavior, conflicts, pedestrian gap acceptance and crossing times, vehicle counts, and group/cluster information.

The group/cluster information was simply copied from the handwritten sheet completed on site to the spreadsheet file

Figure 19. Measuring dimensions at a study site.

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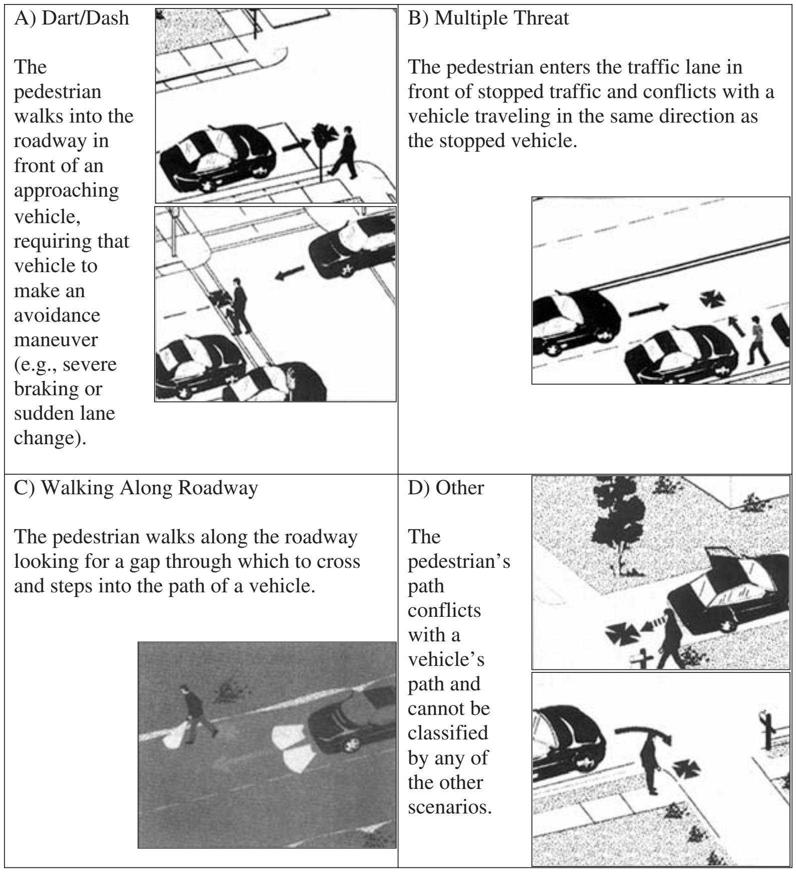

Figure 20. Definition of conflict categories (Adapted from* Pedestrian Facilities User Guide–Providing Safety and Mobility *[27]).

for storage. The vehicle counts were completed by watching the videotapes and counting the vehicles traveling through the study site. These counts were divided into 5-minute periods in each direction of vehicle travel. The remaining items were reduced with a combination of the PDA data and the video recordings.

In the spreadsheet file, worksheets were created for manually recording motorist behavior, conflicts, and gap and crossing data. Technicians would then review the video for a site and record the pertinent information for each crossing event, correlating each event to a recorded event in the PDA data when possible. At each site, however, there were crossing events not recorded in the PDA on site; these events were added to the spreadsheet.

The motorist behavior information collected for a particular crossing event included the PDA record number (if applicable), the crossing number (a count of both PDA records and events not in the PDA), the number of pedestrians (if a group or cluster), the motorist compliance behavior in both directions of travel, the stopping distance for vehicles in both directions of travel, and comments about the behavior of the pedestrian.

Conflict information was a determination of whether a conflict occurred during the crossing event and, if so, what type of conflict it was. Conflicts were defined by one of four general categories, as shown in Figure 20. Most crossing events occurred without conflicts.

Reducing gap and crossing data involved observing each crossing event with respect to the time the pedestrian arrived at certain points along the crossing route. The crossing behavior was also recorded, as were any comments by the observer. Five distinct times were recorded for each pedestrian, as defined in Figure 21. For vehicles that passed through the site during a crossing event, their time of arrival and travel lane were recorded.

Summary

The research used observational studies of motorist and pedestrian behavior to evaluate the effectiveness of pedestrian crossing treatments at 42 sites in seven states. Several measures of effectiveness were used as surrogates for safety performance, because the timing and duration of the study did not

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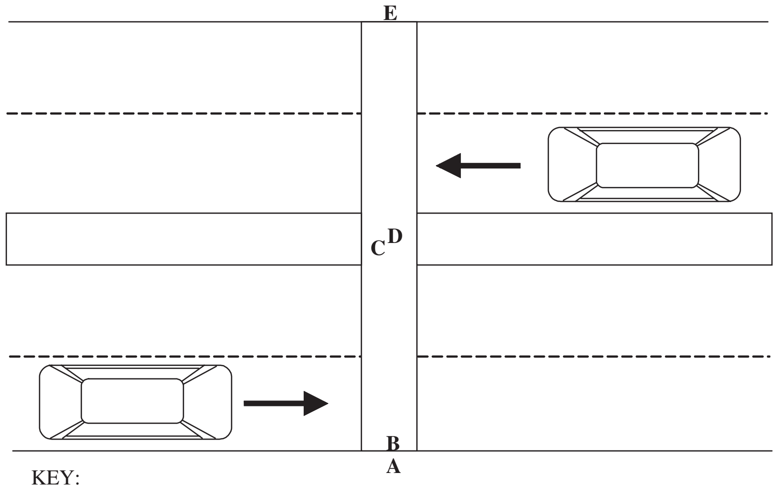

KEY:
A = pedestrian approaches curb, indicates interest to cross
B = pedestrian steps off of near side curb
C* = pedestrian reaches middle of median
D* = pedestrian departs middle of median
E = pedestrian steps onto far side curb

*C and D are omitted for sites with no median.

Figure 21. Crossing diagram.

permit the collection of before-and-after pedestrian crash data at several promising study sites. Several criteria were used to select the study sites, chief among them: presence of a marked crosswalk, pedestrian activity, proximity to transit stops, and high-volume, high-speed streets. The study sites were grouped into three categories according to function and design: red signal or beacon devices (e.g., half signals and HAWK); “active when present” warning devices (e.g., flashing beacons or crossing flags); and enhanced and/or high-visibility signs and markings. Videocameras were placed at inconspicuous locations to provide a permanent record of pedestrian and motorist behavior at each study site. Members of the research team also staged crossings at each site to provide a consistent reference point for comparison among all sites. Palmtop computers were used on site to record certain pedestrian and motorist behaviors not easily extracted from video. The research team also gathered data about site conditions (e.g., geometry and dimensions in vicinity of crossing). These field studies provided a comprehensive, multi-faceted dataset that permitted a wide variety of analyses.

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CHAPTER 7

Findings From the Field Study

The field data provided information on several pedestrian and motorist behaviors. This chapter summarizes those findings.

For specific variables, the following data reduction protocol was used. For pedestrians crossing in groups and clusters, observers only considered the leading pedestrian or the pedestrian closest to the oncoming traffic. All pedestrians in a group or cluster were counted as a single pedestrian crossing event. For the dataset of 3,155 crossings, 74 percent of the observations represented crossings of individuals, 18 percent were groups (over three-fourths being groups of two), and 8 percent were clusters (most of which occurred at sites showing a red indication, i.e., pedestrians are restricted by pedestrian signal indications).

Non-staged (or general population) pedestrians were represented in the descriptive statistics presented in this chapter. For computing motorist compliance rates, the staged pedestrians were also used.

Walking Speed

One of the pedestrian characteristics collected during field studies conducted as part of this TCRP/NCHRP study was the time for the pedestrian to cross to the middle of the street or median and then to the other side of the street. Using the distances being traversed, the walking speeds of the pedestrians were determined. The walking speeds associated with different roadway conditions and pedestrian characteristics are available from the dataset. Various statistical analyses were used to better understand walking speed and to explore its relationship with the roadway environment and pedestrian characteristics. Appendix N provides more details on walking speed findings. This section provides a summary.

Pedestrian Walking Speed by Age Groups

To permit comparisons with other studies, the data were grouped to reflect the following:

- Young—consists of pedestrians between the ages of 13 and 60, and
- Old—includes pedestrians older than 60.

The gender of the pedestrian was also recorded if the technician was able to determine the information from the field observation or later in the office during the video data reduction effort.

A total of 3,155 pedestrian crossings were recorded during this study. Of that, 81 percent (2,552 pedestrians) were observed as "walking." The remaining 19 percent of the pedestrians (603) were observed to be running, both walking and running during the crossing, or using some form of assistance (e.g., skates or bicycles). These 603 data points were not included in the following analyses. Also not included in the analyses were the 107 walking pedestrians whose ages could not be estimated and the 6 pedestrians whose genders could not be determined.

Table 18 lists walking speeds by age group and gender. The walking speed values for older pedestrians are lower than those for younger people. For young pedestrians, the 15th percentile walking speed was 3.77 ft/s (1.15 m/s). Older pedestrians had a slower walking speed with the 15th percentile being 3.03 ft/s (0.9 m/s). The average walking speed was 4.25 and 4.74 ft/s (1.3 and 1.45 m/s) for old and young pedestrians, respectively. Figure 22 illustrates the distribution of the walking speeds along with the current MUTCD walking speed and the walking speed recommended by the U.S. Access Board (*57*).

Age Group Comparison

An F test was used to find out if the walking speeds by gender and age were statistically different. Table 19 shows the results of the tests. The male, female, and combined male and female older pedestrian groups had 15th percentile walking speeds that were statistically different from the 15th percentile walking speeds of the younger pedestrians. For example, the 15th percentile walking speed of 3.03 ft/s (0.9 m/s) for older

Table 18. Walking speed by gender and age group.

Age Groups	Walking Speed, ft/s (m/s)		
	Sample Size	15th Percentile	50th Percentile
		Male	
Young	1434	3.75 (1.14)	4.78 (1.46)
Old	75	3.11 (0.95)	4.19 (1.28)
ALL	1509	3.67 (1.12)	4.75 (1.45)
		Female	
Young	890	3.79 (1.16)	4.67 (1.42)
Old	31	2.82 (0.86)	4.41 (1.34)
ALL	921	3.75 (1.14)	4.67 (1.42)
		Both Genders	
Young	2324	3.77 (1.15)	4.74 (1.45)
Old	106	3.03 (0.92)	4.25 (1.30)
ALL	**2430**	**3.70 (1.13)**	**4.72 (1.44)**

pedestrians was statistically different from the 15th percentile walking speed of 3.77 ft/s (1.15 m/s) for younger pedestrians. For the comparison done with the 50th percentile walking speeds, the female groups did not show a statistical difference. It is believed that this lack of difference was influenced by the small number of older women within the study set (only 31 older women pedestrians).

In most cases, the walking speeds of the male and female pedestrian groups were similar. The only statistical difference in gender among the age groups was for the 50th percentile walking speed of the young group as shown in Table 19. The young female group walked slightly slower (4.67 ft/s [1.4 m/s]) than the young male group (4.78 ft/s [1.5 m/s]).

Comparison of TCRP/NCHRP Walking Speed Findings with Previous Work

As documented in Appendix M, several studies have examined walking speed, including

- *Manual on Uniform Traffic Control Devices for Streets and Highways* (*1*),

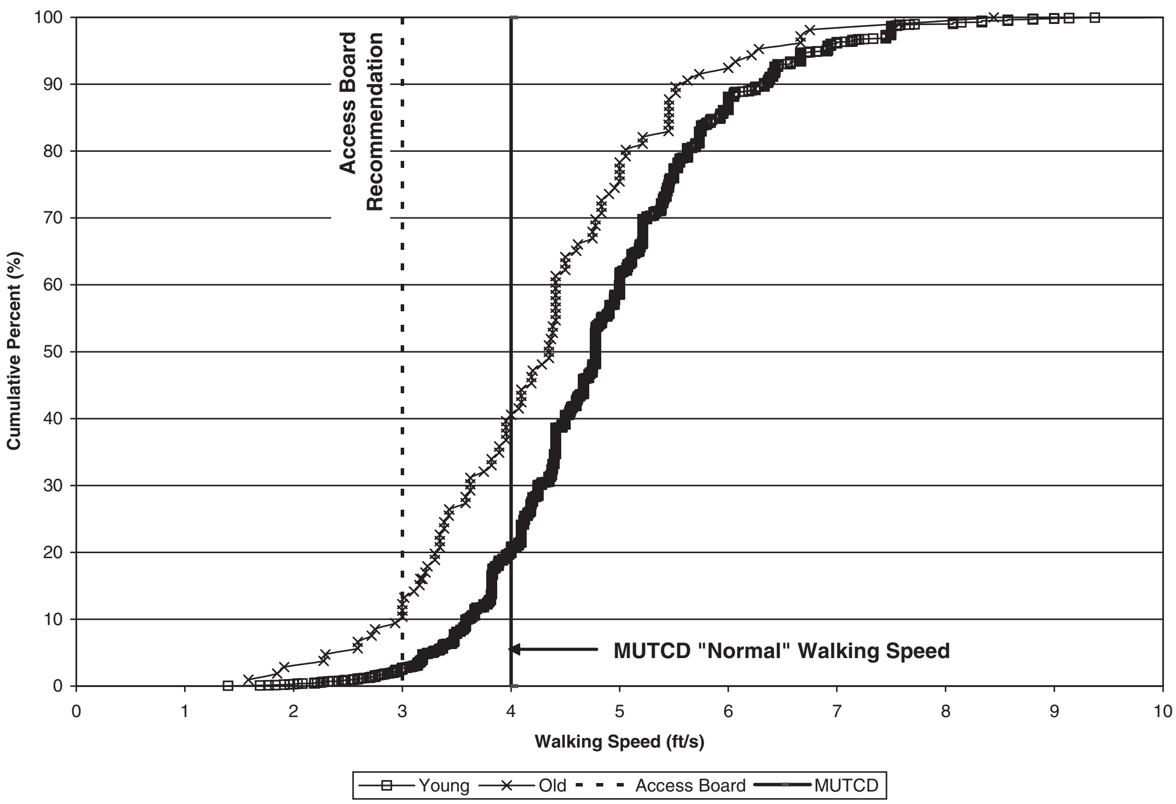

Figure 22. Older than 60 (Old) and 60 and younger than 60 (Young) walking speed distribution.

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Table 19. F-test results for gender and age group walking speed comparisons.

Comparison	15th Walking Speed (ft/s)		F 15th	P	50th Walking Speed (ft/s)		F 50th	P	$F_{1,n-1,0.05}$
Male, Old & Young	**3.11**	**3.75**	**22.59**	**0.0001**	**4.19**	**4.78**	**19.2**	**0.0001**	3.85
Female, Old & Young	**2.82**	**3.79**	**24.8**	**0.0001**	4.41	4.67	1.78	0.1825	3.85
Both Age Groups Male & Female	3.67	3.75	2.91	0.0882	4.75	4.67	2.91	0.0882	3.84
Old Male & Female	3.11	2.82	2.67	0.1053	4.19	4.41	1.54	0.2174	2.91
Young Male & Female	3.75	3.79	0.70	0.4029	**4.78**	**4.67**	**5.31**	**0.0213**	3.84
Both Genders Old & Young	**3.03**	**3.77**	**35.25**	**0.0001**	**4.25**	**4.74**	**14.96**	**0.0001**	3.84

Bold cells indicate the walking speeds are different between the comparison groups.

- Public Rights-of-Way Access Advisory Committee draft 2002 guidelines (*57*),
- LaPlante and Kaeser (*58*),
- 1982 *Transportation and Traffic Engineering Handbook* (*59*),
- Knoblauch et al. (*14*),
- Guerrier and Jolibois (*60*),
- Milazzo et al. (*61*),
- 2000 *Highway Capacity Manual* (*23*),
- 2001 *Traffic Control Devices Handbook* (*62*),
- *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians* (*63*),
- Dahlstedt (*11*) in a study in Sweden,
- Coffin and Morrall (*12*),
- Dewar (*8*) in *Human Factors in Traffic Safety*,
- Bennett et al. (*9*) in a 2001 Australian Institute of Transportation study, and
- Akçelik & Associates (*64*) in a 2001 Australian study.

Most of the studies have provided values at the 15th percentile level. The 15th percentile level is frequently used to set policy for roadway design or traffic operations, but not in every situation. The portion of the population to include in calculating the 15th percentile value also varies. For example, in setting driver eye height values for use in stopping sight distance, the question of whether to include the higher eye heights represented by trucks and by drivers in sport utility vehicles (SUVs) was debated. (For the final determination, values for trucks and SUVs were not included in setting the design driver eye height; see *NCHRP Report 400*[*65*].)

A similar debate exists for walking speed. Should "walking speed" include all crossing maneuvers, even if the pedestrian is running? Should those using some form of wheels, whether it be in-line skates or a wheelchair, be considered? Should design be based only on older pedestrians or a mix of older and younger pedestrians?

Figure 23 summarizes the 15th percentile findings from several studies. The figure also includes key characteristics of the study, such as whether the data reflect old or young pedestrians. As shown in Figure 23, previous work has identified or recommended walking speeds as low as 2.2 ft/s (0.7 m/s) and as high as 4.27 ft/s (1.3 m/s) for a 15th percentile value. Two studies with databases known to include over 2,000 pedestrian crossings are the 1996 Knoblauch et al. study (*14*) with data collected in 1993 and this TCRP/NCHRP study with data collected in 2003. Table 20 summarizes the findings for young, old, and all pedestrians from these two studies.

Based on their findings, Knoblauch et al. suggested a value of 4.0 ft/s (1.22 m/s) for younger pedestrians and 3.0 ft/s (0.9 m/s) for older pedestrians for traffic signal design. The U.S. Access Board has recommended a walking speed of 3.0 ft/s (0.9 m/s). LaPlante and Kaeser (*58*) in a September 2004 *ITE Journal* article recommended 3.5 ft/s (1.1 m/s) minimum walking speed for curb-to-curb for determining the pedestrian clearance interval and 3.0 ft/s (0.9 m/s) walking speed from top of ramp to far curb for the entire walk plus pedestrian clearance signal phasing.

This TCRP/NCHRP study had a similar number of young pedestrians within the dataset as the 1993 study (over 2,000 pedestrians). The TCRP/NCHRP study, however, found a slower walking speed (3.77 ft/s [1.15 m/s], as compared with 4.02 ft/s [1.23 m/s]). Therefore, the findings do not support the suggestion of a 4.0 ft/s (1.22 m/s) walking speed for traffic signal design. If both older and younger pedestrians are considered, the TCRP/NCHRP study found 3.7 ft/s (1.13 m/s), while the larger 1993 study found 3.53 ft/s (1.08 m/s). Based on the larger number of older pedestrians included in the 1993 study, a recommendation of 3.5 ft/s (1.1 m/s) for the timing of a traffic signal design seems more reasonable. If older pedestrians are a concern at the intersection, then a signal timing design using a 3.0 ft/s (0.9 m/s) walking speed is suggested.

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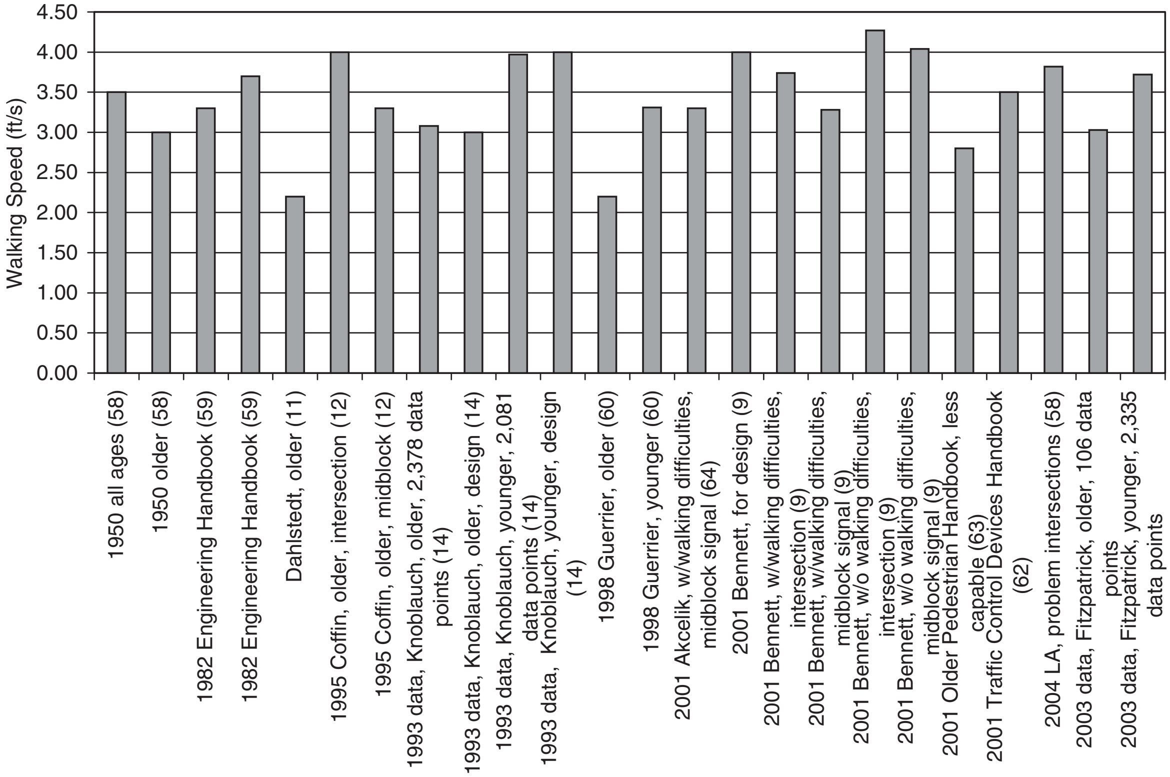

Figure 23. Comparison of findings from previous studies for 15th percentile walking speed (labels contain year of study or year data were collected if known, authors or abbreviation of title, characteristics of study if relevant, and reference number in parentheses).

Conclusions

Comparing the findings from this TCRP/NCHRP study with previous work resulted in the following recommendations:

- 3.5 ft/s (1.1 m/s) walking speed for the general population; and
- If older pedestrians are a concern, use a 3.0 ft/s (0.9 m/s) walking speed.

Motorist Compliance

This section presents the study findings on the effectiveness of pedestrian crossing treatments at unsignalized intersections as measured by motorist compliance (yielding or stopping as required by law). This section also describes an analysis of street and traffic characteristics (e.g., speed limit, number of lanes, and traffic volumes) that influence motorist compliance at marked crosswalks at unsignalized intersections. More details are included in Appendix M.

Summary of Motorist Yielding Rates

Tables 21 and 22 summarize the measured motorist yielding data from both types of pedestrian crossings (general population and staged), including comparable evaluation data from the literature where available. The results are grouped into the three basic categories of pedestrian crossing treatments used in the study. The range column in the table

Table 20. Walking speed by age groups for Knoblauch et al. and TCRP/NCHRP studies.

Age Group	Walking Speed (ft/s)					
	Knoblauch et al.			TCRP/NCHRP		
	Sample Size	15th Percentile	50th Percentile	Sample Size	15th Percentile	50th Percentile
Young	2081	4.02	4.79	2335	3.77	4.74
Old	2378	3.10	3.94	106	3.03	4.25
All	4459*	3.53*	4.34*	2441	3.70	4.72

***Calculated using values provided in Knoblauch et al. paper (*14*).**

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Table 21. Summary of motorist yielding compliance from three sources for red signal or beacon and active when present.

Crossing Treatment	TCRP D-08/NCHRP 3-71 Study: Compliance – Staged Pedestrian Crossing # of Sites	Range (%)	Average (%)	TCRP D-08/NCHRP 3-71 Study: Compliance – General Population Pedestrian Crossing # of Sites	Range (%)	Average (%)	Other Studies: Compliance – Literature Review (from Table L-1) # of Sites	Range (%)	Average (%)
Red Signal or Beacon									
Midblock Signal	2	97 to 100	99%	4	91 to 98	95%	NA	NA	NA
Half Signal	6	94 to 100	97%	6	96 to 100	98%	1	99	99%
HAWK Signal Beacon	5	94 to 100	97%	5	98 to 100	99%	1	93	93%
Active When Present									
In-Roadway Warning Lights	NA	NA	NA	NA	NA	NA	11	8 to 100	66%
Overhead Flashing Beacon (Pushbutton Activation)	3	29 to 73	47%	4	38 to 62	49%	10	13 to 91	52%
Overhead Flashing Beacon (Passive Activation)	3	25 to 43	31%	3	61 to 73	67%	NA	NA	74%
Pedestrian Crossing Flags	6	46 to 79	65%	4	72 to 80	74%	NA	NA	NA

Notes: "NA" indicates that data were not collected or available in the literature.
The "Range" column represents the range of motorist yielding for all sites with the treatment.
The "Average" column represents the average value of motorist yielding for all sites with the treatment.

Table 22. Summary of motorist yielding compliance from three sources for enhanced and/or high-visibility treatments.

Crossing Treatment	TCRP D-08/NCHRP 3-71 Study: Compliance – Staged Pedestrian Crossing # of Sites	Range (%)	Average (%)	TCRP D-08/NCHRP 3-71 Study: Compliance – General Population Pedestrian Crossing # of Sites	Range (%)	Average (%)	Other Studies: Compliance – Literature Review (from Table L-1) # of Sites	Range (%)	Average (%)
Enhanced and/or High-Visibility									
In-Street Crossing Signs (25 to 30 mph [40 to 48 km/h] Speed Limit)	3	82 to 91	87%	3	84 to 97	90%	7	44 to 97	77%
High-Visibility Signs and Markings (35 mph [55 km/h] Speed Limit)	2	10 to 24	17%	2	4 to 35	20%	NA	NA	NA
High-Visibility Signs and Markings (25 mph [40 km/h] Speed Limit)	1	61	61%	1	91	91%	1	52	52%
Median Refuge Islands	6	7 to 75	34%	7	7 to 54	29%	NA	NA	NA

Notes: "NA" indicates that data were not collected or available in the literature.
The "Range" column represents the range of motorist yielding for all sites with the treatment.
The "Average" column represents the average value of motorist yielding for all sites with the treatment.

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represents the range of average compliance values for the sites with that treatment. If a site had less than 10 general population pedestrians crossing the street during data collection, the compliance values were not included in summary statistics. The average column represents the average compliance rate for all sites with that treatment.

The research team prepared these findings from Tables 21 and 22:

- The motorist compliance rates for staged pedestrians and general population pedestrians were in relatively close agreement for most crossing treatments. Only two crossing treatments (total of four study sites) had motorist yielding rates with a greater than 10 percent difference between general population and staged pedestrians. At three Los Angeles sites, the research team attributed the differences to general population pedestrians who routinely stepped off the curb while waiting, whereas staged pedestrians did not step off the curb until motorists yielded. At a single Tucson site, the general population pedestrian flow was fairly heavy, which could lead to two possible explanations: (1) motorists were more likely to yield to larger groups of pedestrians than the single staged pedestrian and (2) the larger groups of pedestrians could have been more assertive in claiming the crosswalk right-of-way. Because the behavior of the staged pedestrians was consistent among all sites, these compliance rates are used in further analyses.
- Red signal or beacon treatments consistently perform well, with compliance rates above 94 percent. The research team concluded that these treatments are effective because they send a clear regulatory message (a red signal means "Stop") to motorists that they must stop for pedestrians. Nearly all the red signal or beacon treatments evaluated were used on busy, high-speed arterial streets.
- Pedestrian crossing flags and in-street crossing signs also were effective in prompting motorist yielding, achieving 65 and 87 percent compliance, respectively. However, many of these crossing treatments were installed on lower-volume, two-lane roadways. It has been suggested that motorists are more likely to yield to pedestrians crossing narrow, low-volume and low-speed roadways. This is supported by the difference in compliance for high-visibility signs and markings. On streets with a 35-mph (55-km/h) speed limit, the average compliance rate was 17 percent; however, on streets with a 25-mph (40-km/h) limit, the average compliance rate was 61 percent (although only a single site had this speed limit).
- The measured compliance rates for many crossing treatments varied considerably among sites. For example, treatments in the "active when present" and "enhanced and/or high-visibility" categories have a wide range of compliance rates as shown in Tables 21 and 22. The research team concluded that other factors (e.g., traffic volume, roadway width, and street environment) were affecting compliance rates. These factors are discussed in more detail in Appendix L.

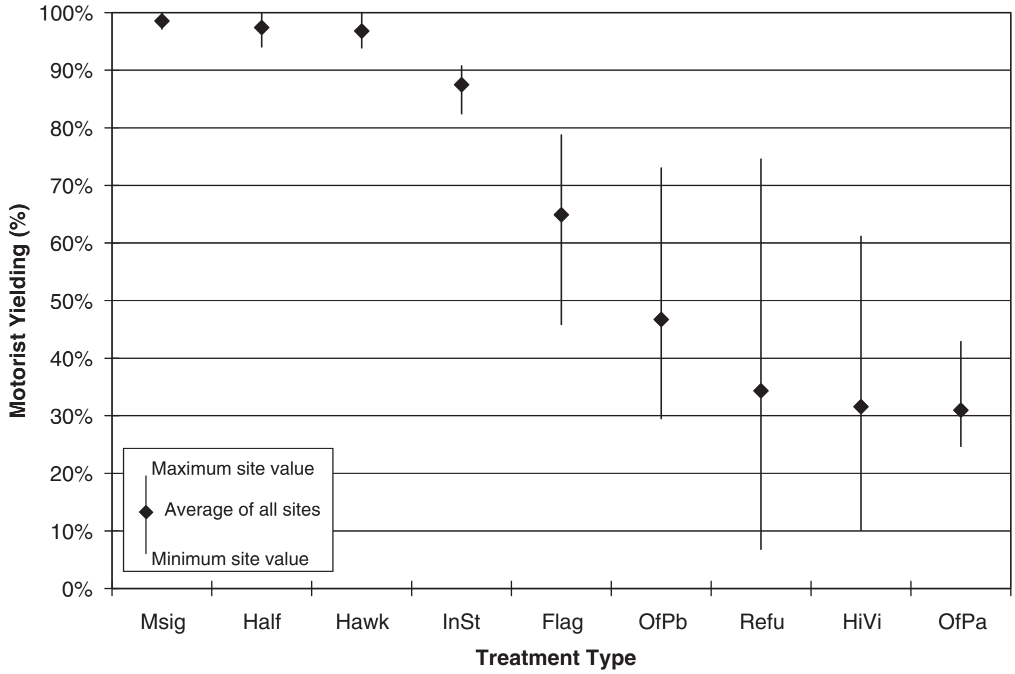
Significant Differences in Treatment Effectiveness

As indicated in the previous section, many crossing treatments had wide ranges in the measured compliance rate (see Figure 24). Thus, even though the average compliance may be greater for some treatments, the wide range in compliance does not mean that one treatment is statistically more effective than others. The research team tested statistical differences of compliance rates between the crossing treatments using two different methods:

- Analysis of variance—determines whether the mean compliance rates of the crossing treatments are statistically different and
- Multiple comparisons test—uses Tukey's "honestly significant differences" (HSD) test to find out which crossing treatments have statistically similar mean compliance rates.

The findings of the statistical analyses are summarized as follows:

- The three devices designated as red signal or beacon had statistically similar mean compliance rates. These devices include the midblock signal, half signal, and HAWK signal beacon. All three devices had average compliance rates greater than 97 percent. These statistical results validate the research team's approach of grouping these devices into the same "red signal or beacon" category.
- Many crossing treatments in the "active when present" and "enhanced and/or high-visibility" categories had compliance rates that were not statistically different than other treatments. Only three treatments were statistically different from others in these categories. The compliance rate for in-street crossing signs was statistically different than compliance rates for high-visibility signs and markings and overhead flashing beacons (pushbutton activation). The research team concluded that it may still be appropriate to differentiate between the "active when present" and "enhanced and/or high-visibility" treatments when discussing function. However, the statistical results indicated that nearly all treatments in these two categories did not have statistically significant differences between the mean compliance rates.



Abbreviations: Msig=midblock signal; Half=half signal; Hawk=HAWK signal beacon; InSt=in-street crossing signs; Flag=pedestrian crossing flags; OfPb=overhead flashing beacons (pushbutton activation); Refu=median refuge island; HiVi=high-visibility signs and markings; OfPa=overhead flashing beacons (passive activation)

Figure 24. Site average and range for motorist yielding by crossing treatment.

Street Characteristics That Influence Treatment Effectiveness

Because of the wide range in measured compliance rates among sites, the research team hypothesized that other variables were influencing the treatment effectiveness. For example, an in-street crossing sign installed on a wide, high-speed arterial would likely produce a lower compliance rate than if installed on a narrow, lower-speed collector street. The research team performed a qualitative analysis and a statistical analysis of covariance to find those factors that most affected the range in compliance rates.

Effect of Number of Lanes

The top chart in Figure 25 shows the motorist yielding by treatment type (major grouping) and number of lanes. For the "red signal or beacon" devices, the number of lanes did not affect performance. Within the study set, red devices were on two-, four-, and six-lane roadways. A compliance rate above 94 percent exists, regardless of the number of lanes on the facility. The half signal treatment had statistically the same compliance rate for both two and four lanes. The same result was true for the HAWK treatment on four- and six-lane roads.

Pedestrian crossing flags did not show a statistically different mean compliance for locations with a different number of lanes. The flags on two-, four-, and six-lane highways had statistically similar compliance rates. Median refuge islands were the only treatment with statistically different compliance values based on the number of lanes.

The bottom chart in Figure 25 regroups the data in the top chart of Figure 25 by number of lanes. As seen in the bottom chart of Figure 25 for four-lane highways, the red devices have a much higher compliance rate than the other non-red devices. All but one of the devices on a two-lane roadway performed at better than a 60-percent compliance rate.

The statistical analysis of covariance also indicated that the number of lanes crossed was a statistically significant variable (at the 0.05 level) in predicting motorist yielding at treatments.

Effect of Speed Limit

Figure 26 shows motorist yielding by treatment type and speed limit. As seen in the top chart of Figure 26, in-street pedestrian crossing signs and overhead flashing beacons (pushbutton activation) appear to have an increase in compliance with an

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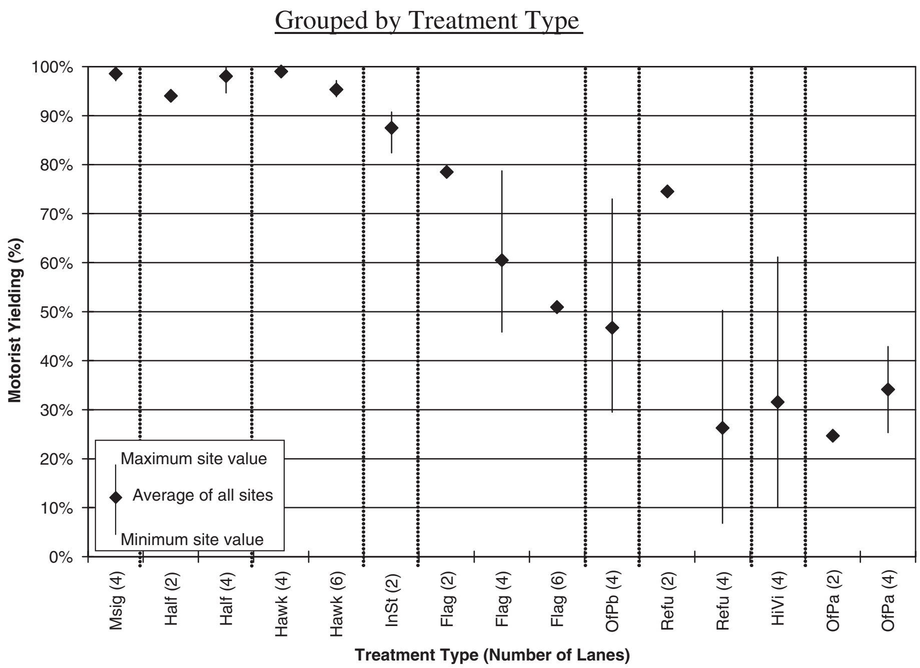

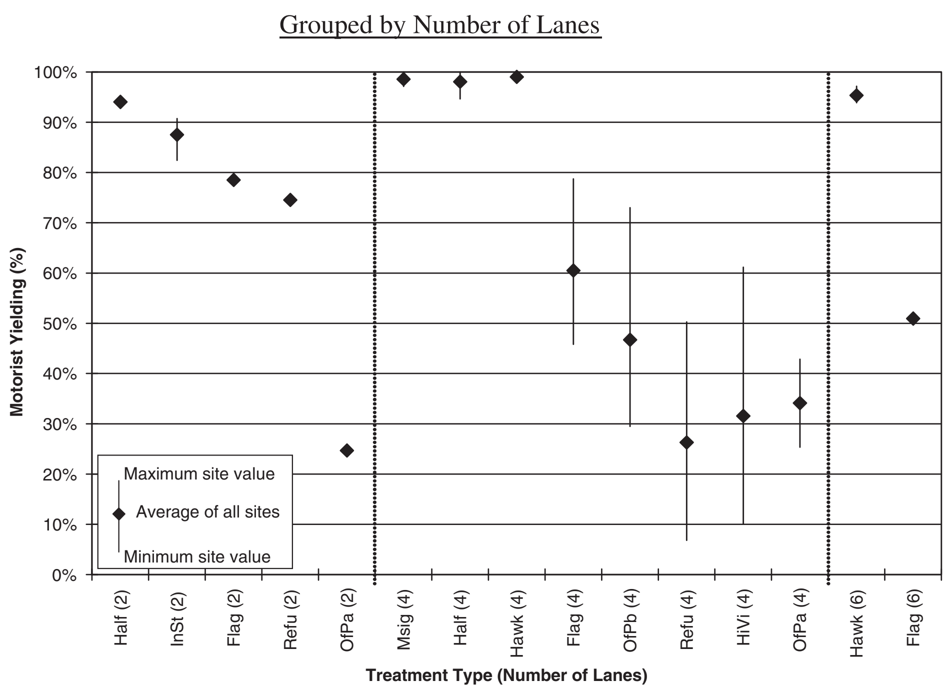

Abbreviations: Msig=midblock signal; Half=half signal; Hawk=HAWK signal beacon; InSt=in-street crossing signs; Flag=pedestrian crossing flags; OfPb=overhead flashing beacons (pushbutton activation); Refu=median refuge island; HiVi=high-visibility signs and markings; OfPa=overhead flashing beacons (passive activation)

Figure 25. Motorist yielding by crossing treatment and number of lanes.

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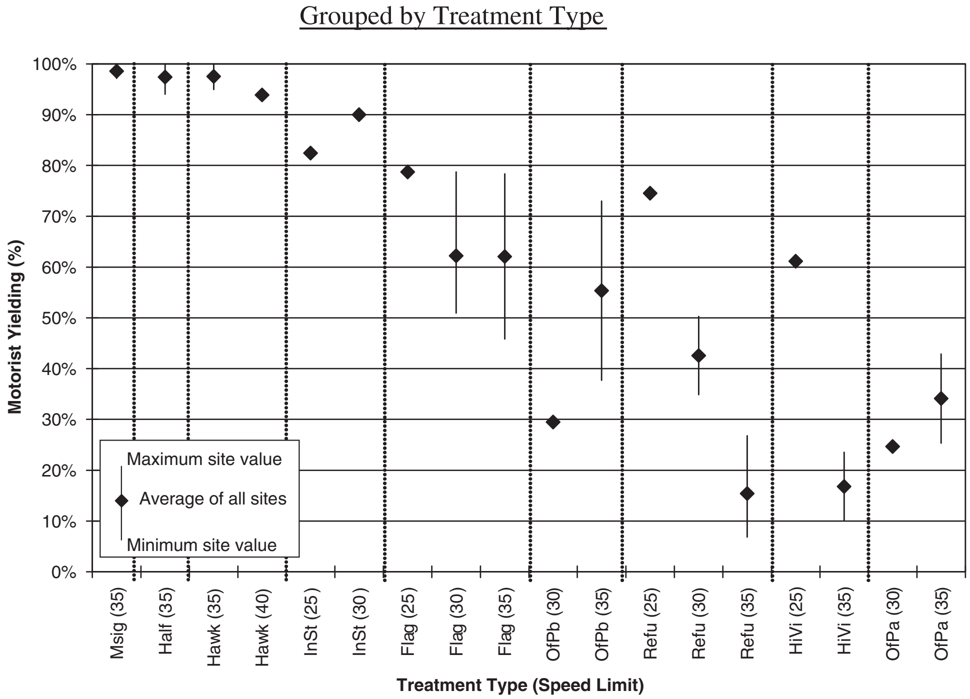

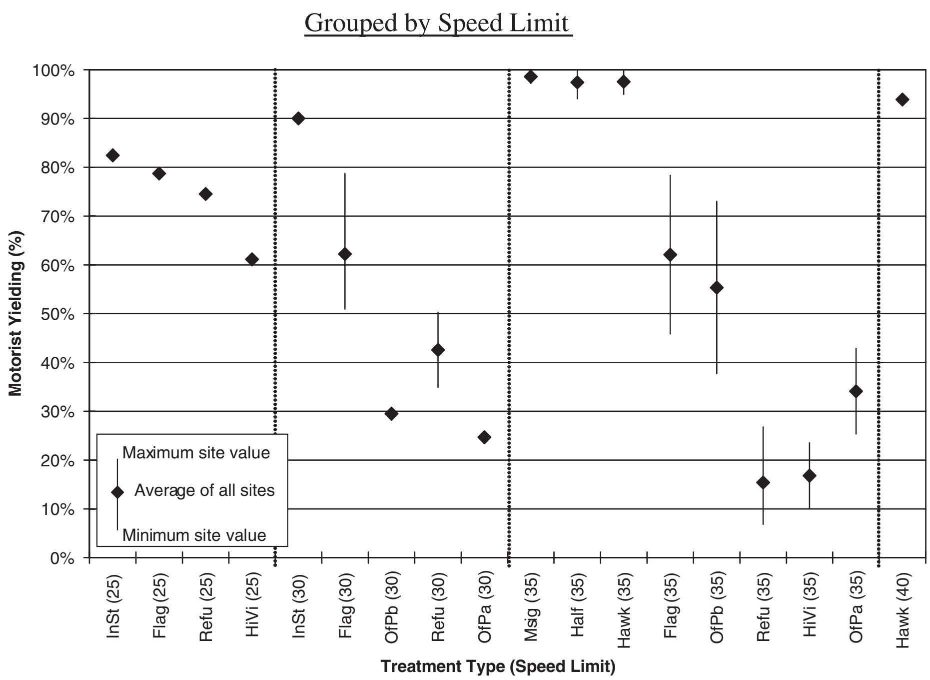

Abbreviations: Msig=midblock signal; Half=half signal; Hawk=HAWK signal beacon; InSt=in-street crossing signs; Flag=pedestrian crossing flags; OfPb=overhead flashing beacons (pushbutton activation); Refu=median refuge island; HiVi=high-visibility signs and markings; OfPa=overhead flashing beacons (passive activation)

Figure 26. Motorist yielding by crossing treatment and posted speed limit.

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increase in speed; however, the average compliance rates are not statistically different. In other words, the performance at these two devices is independent of the posted speed limit. The performance of the overhead flashing beacons (passive activation) shows a statistically different compliance rate between the device on the 30-mph (48-km/h) roadway and the device on the 35-mph (55-km/h) roadway, with the device on the higher-speed roadway having a higher compliance rate. Reviewing the specific sites showed that the 30-mph (48-km/h) site was in a commercial area while the 35-mph (55-km/h) site was in a residential area. Given that other devices show a decrease in compliance with an increase in speed limit, the findings for overhead flashing beacons (pushbutton activation) may be an anomaly.

The median refuge island and high-visibility marking sites all had decreases in compliance rates with increases in speed limit. The F-statistical tests revealed that the compliance rates were statistically different, which indicates that the speed limit affects the performance of the device. Flags, refuge islands, and high-visibility markings all perform better on the lower-speed roadways.

Figure 26 shows a clear break between two groups of treatments at the 35-mph (55-km/h) speed limit. The most effective treatments are all red signal or beacon devices. On a 35-mph (55-km/h) roadway, the best compliance rate observed for a treatment not showing a red indication to the motorist is about 63 percent. Compliance rates go as low as 8 percent for the 35-mph (55-km/h) speed limit group. For the 25-mph (40-km/h) speed limit roadways, all the devices have a high compliance (greater than 60 percent).

The statistical analysis of covariance also indicated that the posted speed limit was a statistically significant variable (at the 0.10 level) in predicting treatment compliance when accounting for interaction between other model variables.

Gap Acceptance

This section summarizes the findings on characteristics of gap acceptance behavior as observed at the field study sites. Appendix N contains more discussion and findings.

The analysis of gap acceptance data had two components: behavioral analysis and statistical analysis. The former was concerned with identifying actions and patterns that pedestrians commonly use in crossing events. The latter was intended to provide a mathematical model to determine gap size for a proportion of the crossing population.

Behavioral Analysis

Specific behavioral patterns affect how data are presented. One particular pattern is the concept of the "rolling gap." During data reduction, gap lengths were measured based on the times when vehicles entered the crosswalk. At certain sites, particularly sites with high volumes of traffic, pedestrians did not wait to cross the street when all lanes were completely clear. Rather, they anticipated that the lanes would clear as they crossed and used a "rolling gap" to cross the street; essentially, there was a separate gap for each lane of traffic that occurred to coincide with the pedestrian's path across the street.

For example, consider the conditions presented in Figure 27. There is not a sufficient gap for the pedestrian to cross the entire two-lane segment from the curb to the median between approaching vehicles because the traffic volumes are too high

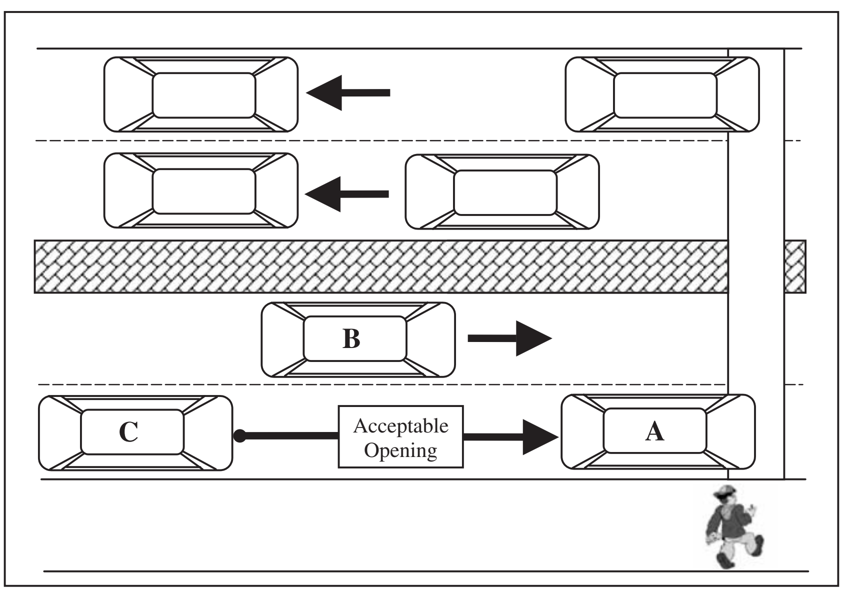

Figure 27. Pedestrian waiting to cross at crosswalk with high traffic volumes.

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and are distributed between both lanes. In the "rolling gap" scenario, the pedestrian would begin the crossing maneuver when the acceptable opening between vehicles A and C occurred in the near (curb) lane, even though a second vehicle (vehicle B) might be approaching in the adjacent lane. However, by the time the pedestrian reaches the adjacent lane, vehicle B has already passed through the crosswalk, leaving an open lane to complete the crossing. After this, another approaching vehicle in the curb lane (vehicle C) might enter the crosswalk, giving the appearance that the actual gap was very small; but if the pedestrian properly timed the crossing, the gap is acceptable to the pedestrian at a comfortable walking speed.

CA-LA-2 is a four-lane divided roadway with a configuration similar to that shown in Figure 27. Under these conditions, there is essentially a separate available gap for each lane that the pedestrian decides to accept or reject. Those gaps may or may not begin or end at the same time, but they occur in such a way that, when taken together, they create a combined gap sufficient for the pedestrian to cross the entire segment. Of the 66 accepted gaps at the CA-LA-2 study site, 60 percent (39 accepted gaps) were "rolling gaps."

Statistical Analysis

The Statistical Analysis Software (SAS) computer program was used to conduct a logit transformation analysis. Each roadway approach was considered individually in the analysis; that is, each site was analyzed separately, and if the roadway was divided at that site, each side of the roadway had a unique analysis. As a result, 47 distinct analyses were performed, in addition to an overall analysis of all gaps for reference.

From these analyses, graphs were generated showing the cumulative distribution of pedestrians accepting gaps of various lengths. Figure 28 shows an example of this type of graph. The data from some sites did not meet the convergence criterion. For the logistic model to run successfully, the values of accepted and rejected gaps must overlap, that is, there should be a gap length (or small range of gap lengths) that was both accepted and rejected. At sites with no overlap in values, the maximum likelihood estimate did not converge, but SAS continued with the analysis and matched a function. Under these conditions, the function does not have the smooth S-curve as shown in Figure 28 but rather resembles a step function, with a straight (and very steep) line between the values of the longest gap rejected and the shortest gap accepted. The results obtained from these functions have a lower level of confidence than the functions where the maximum likelihood estimate existed. This condition is explained in further detail in Appendix N. The complete set of results from the SAS logistical analysis is shown in Table 23.

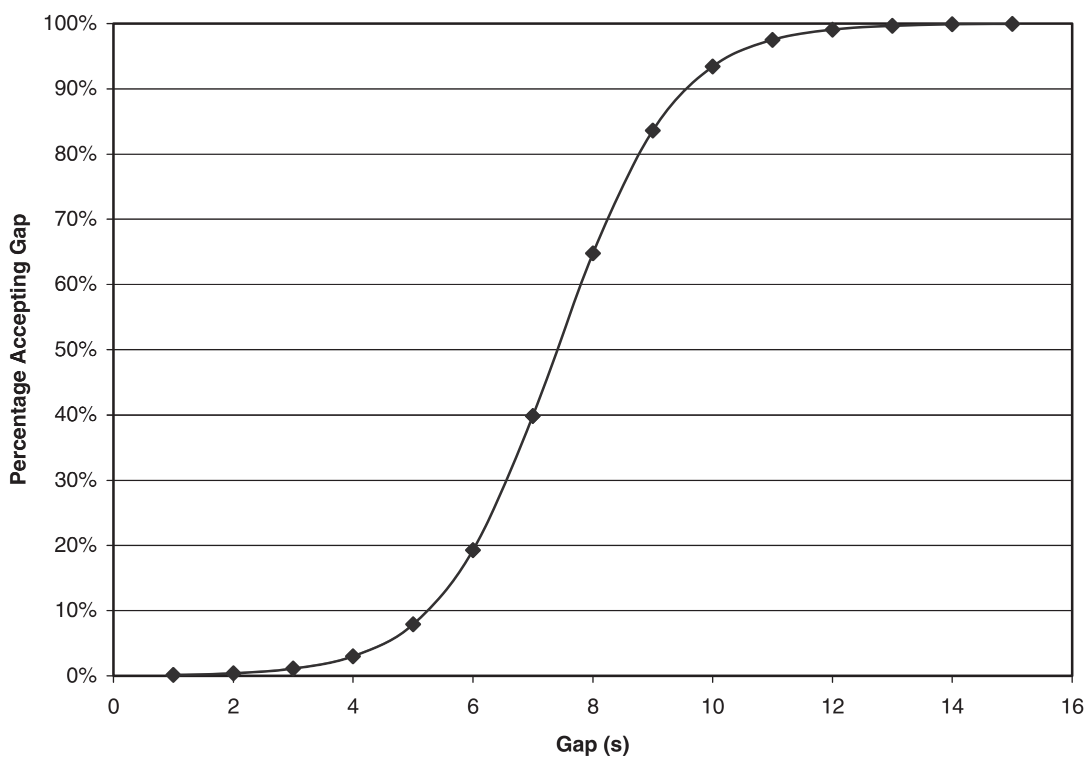

Figure 28. Sample cumulative distribution of gap acceptance.

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Table 23. Result of SAS logistic analysis for approaches with more than 20 pedestrians.

Site	Approach	β'(x)	50th Percentile Gap (s)	85th Percentile Gap (s)	Number of Pedestrians	Maximum Likelihood Estimate Converges?
CA-LA-2	NB 1/SB 2	5.0462-0.8193x	6.2	8.3	34	Y
CA-LA-2	NB 2/SB 1	7.9928-1.5001x	5.3	6.5	32	Y
CA-SM-2	NB 1/SB 2	12.6355-2.4996x	5.1	5.8	40	Y
CA-SM-2	NB 2/SB 1	37.0931-7.2800x	5.1	5.3	30	N
CA-SM-3	NB 1/SB 2	6.9634-1.1879x	5.9	7.3	31	Y
CA-SM-3	NB 2/SB 1	11.8970-2.0942x	5.7	6.5	29	Y
MD-P1	NB 2/SB 1	65.1435-10.6485x	6.2	6.3	21	N
MD-TO-1	NB	6.7212-0.9039x	7.4	9.4	22	Y
MD-TO-1	SB	14.4907-1.7604x	8.2	9.2	34	Y
UT-SL-2	NB	6.2673-1.2341x	5.1	6.5	22	Y
WA-KI-3	WB	42.176-8.7008x	4.8	5.0	22	N
ALL Sites and Approaches		**6.2064-0.9420x**	**6.6**	**8.4**	**512**	**Y**

Findings

Several elements can affect the size of the 85th percentile accepted gap. First, the amount of data can have a significant effect, especially when only a few pedestrians were faced with making a gap acceptance decision. To minimize the potential effect that only a few pedestrians could have on the results, only those approaches with more than 20 pedestrians on the approach were considered in this evaluation.

Second, the distribution of the data can affect the analysis of a large number of data points. At the NB2/SB1 approach of CA-LA-2, there were 241 observed gaps but only 32 pedestrians. Out of these 241 gaps, 196 required the pedestrian to make a gap acceptance decision on a gap of 3 seconds or less while only 10 were gaps of longer than 10 seconds. With such dense traffic, the gap acceptance was skewed lower. The gap acceptance results would be stronger if based only on free-flow vehicles; however, using only free-flow vehicles does not capture the conditions faced by the pedestrian. When the location is within a coordinated corridor, the pedestrian may ignore the gaps within the platoons of vehicles and wait for the larger gap present between the platoons.

Third, the lack of some overlap in the accepted and rejected gaps is an important factor, as mentioned in the analysis section above. If there is separation of data, the maximum likelihood estimate does not converge; however, SAS will still provide an output, which will often have a very large standard error. An example is the NB2/SB1 approach of CA-SM-2, which had 125 observed gaps. An examination of the data reveals that almost all gaps between 1 and 5 seconds were rejected (one 5-second gap was accepted), and all the gaps above 5 seconds were accepted. The logit model tries to match these data with an equation, but because of the complete separation for the accepted and rejected gaps, the equation almost forms a straight vertical line between 5 and 6 seconds where no data exist.

Table 24 lists those approaches whose distribution has separation of data. This table shows the values of the longest gaps rejected by at least 85 percent of pedestrians and of the shortest gaps accepted by at least 85 percent of pedestrians.

Results from the logit model indicate a trend in the 85th percentile accepted gaps, in that the accepted gap increased as crossing distance increased. The trend for the 85th percentile accepted gap is compared with the critical gap for a walking speed of 3.5 ft/s (1.1 m/s) in Figure 23. Inspection of Figure 29 reveals that the observed gaps were less than the calculated critical gap for a walking speed of 3.5 ft/s (1.1 m/s). Thus, the

Table 24. Summary of gap distribution for approaches with separation of data.

Site	Approach	Value of Longest Rejected Gap (s)	Value of Shortest Accepted Gap (s)
CA-SM-2	NB 1/SB 2	4.0	6.0
CA-SM-2	NB 2/SB 1	5.0	6.0
CA-SM-3	NB 2/SB 1	4.0	7.0
MD-P1	NB 2/SB 1	6.0	7.0
MD-TO-1	SB	7.0	10.0
WA-KI-3	WB	4.0	6.0

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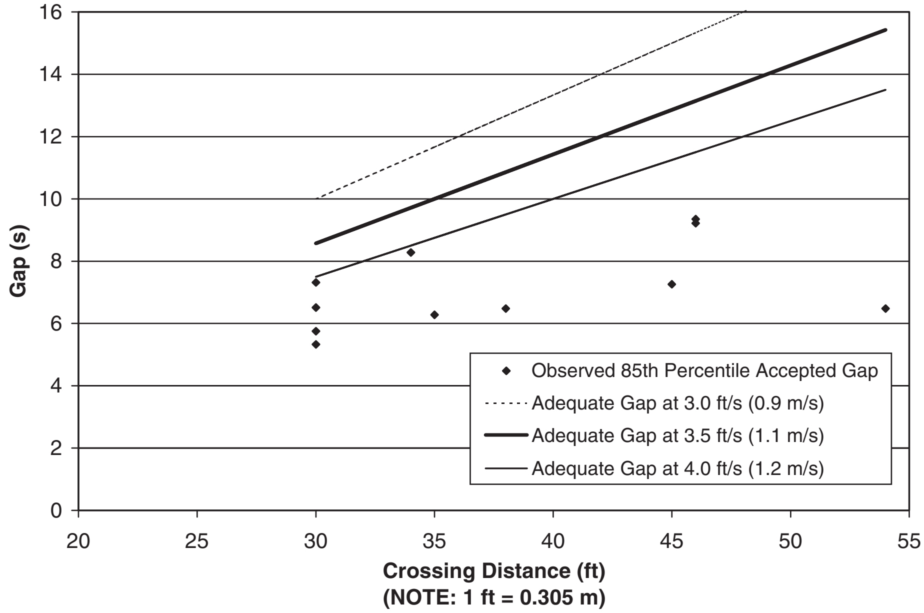

Figure 29. Comparison of trends for observed 85th percentile accepted gaps and calculated critical gaps for walking speeds of 3.0, 3.5, and 4.0 ft/s (0.9, 1.05, and 1.2 m/s).

pedestrians in this study were not consistently accepting gaps exceeding the calculated critical gap, and the 3.5 ft/s (1.1 m/s) design criterion appears sufficient for the pedestrians observed.

Transit Rider Walking Behavior Before Departing

Whether or not a pedestrian was a transit rider was noted as part of the data reduction effects for those sites where a transit stop was within view of the cameras. A total of 878 pedestrians were observed at sites when a transit stop was in camera view with 6 percent (53 pedestrians) being transit riders who boarded a bus and 5 percent (43 pedestrians) being transit riders who alighted from a bus. Of the 53 pedestrians who boarded a bus, the distribution of crossing behavior is listed in Table 25.

About 17 percent of the boarding pedestrians ran or walk/ran through the major roadway crossing before boarding. When the pedestrians who used assistance (e.g., skates or bicycles) are excluded, the percentage of pedestrians who ran or walk/ran becomes 18 percent. For the entire database available from this study on pedestrian crossing behavior, about 14 percent of the pedestrians who did not use assistance either ran or walk/ran through the crossing. In other words, a small but notably larger percentage of transit pedestrians ran or walk/ran as compared with the general population.

The time that each boarding pedestrian waited was determined as the difference between arrival of the pedestrian at the transit stop and the arrival of the bus. The relationship between crossing speed and the wait time is shown in Figure 30. Pedestrians with wait times less than 2 minutes showed the largest range of crossing speeds with the three fastest crossing speeds associated with wait times of less than 0.5 minutes. These pedestrians could be examples of the situation when pedestrians will run because they see an approaching bus. As a contrast to that situation, some of the pedestrians with wait times on the order of 10 minutes also ran or walk/ran in their crossing.

Figure 30 shows a nonlinear relationship between crossing speed and rider wait time with an increasing trend in crossing speed as wait time increases. Researchers attempted to find a statistical relationship. Several transformations were tried on both crossing speed and rider wait time. The no transformation on crossing speed and the log transformation on rider wait time led to the smallest root mean square error (RMSE) when fitting was done by the least squares method. Table 26 contains the estimated coefficients and the corre-

Table 25. Crossing behavior prior to boarding transit.

Number of Pedestrians	Percent (%)	Pedestrian Crossing Behavior (Based on Technician's Judgment)
2	4	Assisted (had skates, bicycles, etc.)
6	11	Ran and walked
3	6	Ran
42	79	Walked
53	100	TOTAL

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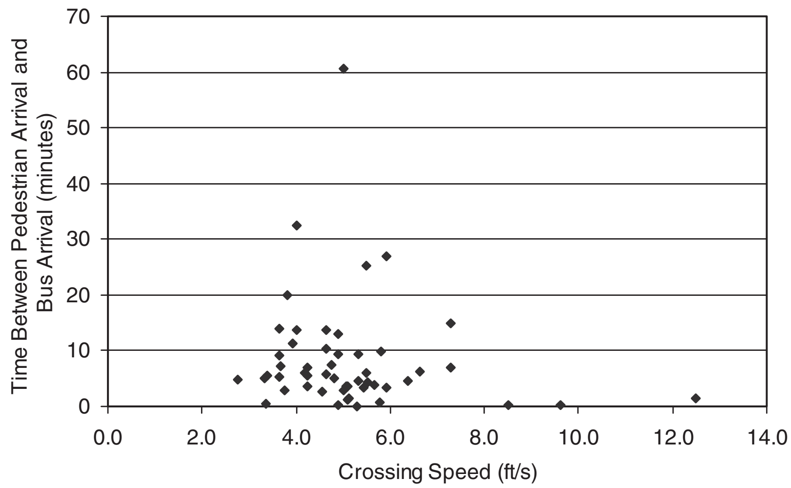

Figure 30. Crossing speed of 53 pedestrians who boarded transit by wait time.

sponding P-values. The P-value for the coefficient estimate of Log (wait time in seconds) is 0.0731, which is at the borderline. At $\alpha = 0.05$, the linear relationship between crossing speed and Log (rider wait time) is not significant, but it is at $\alpha = 0.1$. The prediction equation is given as

$$\text{Crossing speed} = 6.9075 \times 0.3107 \text{ Log (wait time in seconds)}$$

Table 27 shows the R-square value of 0.06 and the adjusted R-square value of 0.04 for the fit in Table 26. As shown in Figure 30, there is considerable variability in crossing speed, which leads to the very low R-square value in Table 27.

Pedestrian Visual Search

Each crossing pedestrian was coded into one of the following categories:

- Looked for oncoming vehicles in each direction (B),
- Looked for oncoming vehicle in one direction only (O),
- Did not look for oncoming traffic in either direction (N), or
- Data could not be determined from the video (X).

Table 28 contains the distribution of pedestrian visual search by treatment. The only treatment where pedestrians only looked in one direction more than 3 percent of the time was the midblock signal; this was because a substantial number of pedestrians tended to look before approaching the pushbutton to activate the signal. After activating the signal, they only watched for the signal indication to cross. The remaining treatments all had about two-thirds or greater of crossing pedestrians looking both ways, except for high-visibility markings and passive overhead beacons, which had a high percentage of unknowns.

Pedestrian Crosswalk Use

Each crossing pedestrian was coded into one of the following categories, showing

- 0—crossed within the crosswalk markings or within 10 ft (3.1 m) of the crosswalk markings for most of the crossing event,
- 1—crossed between 10 and 50 ft (3.1 and 15 m) of the crosswalk markings,
- 2—crossed greater than 50 ft (15 m) from the crosswalk markings, or
- X—data could not be determined from the video.

Table 29 shows the crosswalk use by treatment. Each treatment that showed a red indication to the motorist (e.g., Half, HAWK, or Msig) had between 90 and 95 percent of the pedestrian crossings within 10 ft (3.1 m) of the crosswalk.

Table 26. Least squares fit for crossing speed.

Term	Parameter Estimate	Std Error	t Ratio	Prob>|t|
Intercept	6.9075201	0.962458	7.18	<0.0001
Log(Wait time in seconds)	–0.310708	0.169769	–1.83	0.0731

Table 27. Summary of fit in Table 26.

RSquare	0.06163
RSquare Adjusted	0.04323
Root Mean Square Error	1.672732
Mean of Response	5.196981
Observations (or Sum Weights)	53

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Table 28. Pedestrian visual search by treatment.

	Visual Search				
Treatment	B	N	O	X	Count
Flag	83%	1%	1%	15%	350
Half	79%	1%	2%	17%	342
Hawk	85%	0%	1%	13%	224
HiVi	34%	0%	1%	65%	606
InSt	71%	3%	3%	22%	310
Msig	21%	10%	4%	66%	393
OfPa	47%	2%	2%	49%	164
OfPb	89%	1%	1%	9%	254
Refu	74%	0%	1%	25%	512
Grand Total	62%	2%	2%	35%	3155
Total after removing unknowns	94%	3%	3%	NA	2082

Table 29. Pedestrian crosswalk use by treatment.

	Crosswalk Compliance				
Treatment	0	1	2	X	Count
Flag	88%	5%	7%	0%	350
Half	80%	7%	13%	0%	342
Hawk	90%	5%	5%	0%	224
HiVi	89%	4%	6%	0%	606
InSt	93%	5%	2%	0%	310
Msig	95%	3%	2%	0%	393
OfPa	87%	3%	10%	0%	164
OfPb	82%	2%	16%	0%	254
Refu	82%	13%	5%	0%	512
Grand Total	87%	6%	7%	0%	3155

All other treatments had rates of 80 to 89 percent. If the distance is extended to 50 ft (15 m), all treatments had rates of 84 to 98 percent.

Pedestrian Activation

If the crossing treatment could be activated, each crossing pedestrian was coded into one of the following categories:

- 1—the pedestrian did not attempt to activate the system but had to wait for an acceptable gap;
- 2—the pedestrian did not attempt or was not properly positioned to activate the pedestrian crossing, or an acceptable gap was present when the pedestrian arrived at the curb;
- 3—the crossing treatment was activated by the pedestrian, who waited until the proper time to cross (i.e., Walk signal or flashing light activation);
- 4—the crossing treatment was activated by the pedestrian, who did not wait until the proper time to cross (i.e., Walk signal or flashing light activation); or
- X—data could not be determined from the video.

The distribution of pedestrian activation in Table 30 shows that red devices were activated about two-thirds of the time. Passive yellow devices (OfPa) were activated for

Table 30. Pedestrian activation by treatment.

	Activate					
Treatment	1	2	3	4	X	Count
Flag	35%	46%	8%	9%	2%	350
Half	8%	25%	63%	4%	0%	342
Hawk	13%	15%	69%	1%	2%	224
HiVi	12%	88%	0%	0%	0%	606
InSt	15%	85%	0%	0%	0%	310
Msig	11%	20%	64%	3%	1%	393
OfPa	20%	21%	33%	25%	1%	164
OfPb	27%	43%	22%	6%	1%	254
Refu	44%	53%	0%	0%	3%	512
Grand Total	21%	50%	24%	4%	1%	3155

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Table 31. Pedestrian delay by treatment.

Treatment	Initial Delay (s)		Median Delay (s)		Total Delay (s)		Count
	Avg	StdDev	Avg	StdDev	Avg	StdDev	
Flag	2.67	3.37	0.10	0.37	2.72	3.39	350
Half	16.88	19.78	0.69	3.04	17.06	19.70	342
Hawk	7.80	7.86	1.83	6.21	9.63	9.60	224
HiVi	1.86	4.08	0.53	2.35	2.39	4.88	606
InSt	2.09	3.67	0.09	0.86	2.15	3.78	310
Msig	26.35	27.67	0.00	0.00	26.35	27.67	393
OfPa	5.54	9.47	0.10	1.12	5.62	9.59	164
OfPb	5.44	6.61	--	--	5.44	6.61	254
Refu	5.36	10.20	3.86	11.47	9.22	16.21	512
Grand Total	**8.12**	**15.46**	**1.36**	**6.41**	**9.01**	**16.29**	**3155**

about 60 percent of crossing pedestrians, while active yellow devices were activated 28 percent of the time. Also, about one-half of the pedestrians at a refuge island had no wait, while 85 to 90 percent of pedestrians at other enhanced treatments had no wait.

Of the 67 OfPa pedestrians who had no activation, 27 were at a site where the detector was malfunctioning, 24 were not detected by the system, and 16 were not compliant in using the crosswalk.

Pedestrian-Vehicle Conflicts

A pedestrian-vehicle conflict was counted if either a pedestrian or a vehicle acted to avoid a pedestrian-vehicle collision. Evasive actions by the pedestrian included rushing to complete a crossing or aborting a started crossing. Evasive actions by the vehicle included sudden swerving, lane changing, or braking. Each pedestrian-vehicle conflict was coded into one of the categories shown in Figure 20. In addition the following location for the conflict was recorded:

1. Conflict with the first direction of main street vehicle traffic,
2. Conflict with the second direction of main street vehicle traffic,
3. Conflict with left-turning side street vehicle traffic, or
4. Conflict with right-turning side street vehicle traffic.

Only one conflict was observed in the 3,155 crossings evaluated in this study. That conflict had a car maneuver onto the curb to avoid another car that was stopping for a crossing pedestrian.

Pedestrian Delay

Two types of pedestrian delay were extracted from the videotapes by recording the difference in time between two events, as follows:

- For initial delay, the difference in time between points A and B in Figure 21, recorded as the variable initial delay; and
- For median delay, the difference in time between points C and D in Figure 21, recorded as the variable median delay.

Table 31 summarizes the initial, median, and total pedestrian delay by treatment. Initial pedestrian delay is highest at sites with red treatments, followed by beacons (passive and active) and refuge islands. Sites with flags, high-visibility markings, and in-street signs all had an average initial pedestrian delay lower than 3 seconds. Median pedestrian delay for all sites was very low, except for those with refuge islands. Sites with HAWK signals were the only other sites to have an average median pedestrian delay higher than 1 second.

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CHAPTER 8

Conclusions and Recommendations

This study had two main objectives:

- Recommend selected engineering treatments to improve safety for pedestrians crossing high-volume, high-speed roadways at unsignalized intersections, in particular those served by public transportation; and
- Recommend modifications to the MUTCD pedestrian traffic signal warrant.

The first two sections of this chapter provide conclusions and recommendations for these two main objectives. In accomplishing the two main study objectives, the research team also developed useful supporting information on various aspects of pedestrian safety at unsignalized roadway crossings. This supporting information includes pedestrian characteristics (e.g., walking speed, gap acceptance, and treatment activation behavior), motorist yielding, and traffic engineering and transit agency perspectives. Conclusions and recommendations based on the supporting information are presented in later sections of this chapter.

Guidelines for Pedestrian Crossing Treatments

Summary

The research team developed guidelines for selecting pedestrian crossing treatments for unsignalized intersections and midblock locations (*Guidelines for Pedestrian Crossing Treatments*, included in this report as Appendix A). Quantitative procedures in the guidelines use key input variables (such as, pedestrian volume, street crossing width, and traffic volume) to recommend one of four possible crossing treatment categories:

- Marked crosswalk;
- Enhanced, high-visibility, or "active when present" traffic control device;
- Red signal or beacon device; or
- Conventional traffic control signal.

The guidelines include supporting information for these treatment categories as well as examples and pictures of traffic control devices in each treatment category.

Several traffic engineers tested the guidelines and provided feedback that has been incorporated into the current version. Additionally, the research team tested the guidelines using actual field data from the field study sites as well as other marked crosswalks without treatments. The results of these tests indicated that the guidelines provide appropriate recommendations of pedestrian treatments that substantially agree with engineering judgment.

Recommendation

The research team recommends that the *Guidelines for Pedestrian Crossing Treatments* (included in this report as Appendix A) be widely distributed. The audience and potential users for these guidelines include state, county, and city traffic engineers, transit agencies, roadway designers, and urban planners, as well as consultants for these groups and agencies.

Revisions to the MUTCD Traffic Signal Warrant

Summary

The research team developed and presented recommendations to revise the MUTCD pedestrian warrant for traffic control signals. The proposed revisions were derived from other vehicle-based traffic signal warrants and supplemented with data gathered during the study. The basis for the proposed pedestrian warrant revisions is that the number of pedestrians waiting to cross a street should be no greater than the number of vehicles waiting to cross or enter a street. Once this basis has been accepted, then the existing vehicle-based warrants can be used to derive comparable warrants for crossing pedestrians. The net effect of the proposed revisions is as follows: (1) the pedestrian warrant will be slightly easier to meet with lower pedestrian volumes on streets with high vehicle volumes, and (2) the pedestrian warrant will be slightly more difficult to meet on streets with low vehicle volumes.

In addition to traffic signal warrant revisions, the research team identified two other MUTCD sections that could be revised. The first revision is a minor addition to an enumerated list of alternatives to traffic control signals (MUTCD Section 4B.04). The recommended addition suggests the use of median refuge islands or curb extensions as alternatives to traffic control signals that could improve pedestrian safety. This first revision was accepted by the NCUTCD in January 2006 and could appear in future MUTCD versions (after additional reviews by others). The second recommended revision is the inclusion of a new type of highway traffic signal in the MUTCD called "pedestrian beacon." This revision was endorsed by the Signal Technical Committee in January 2006 and will go to sponsors during the Spring of 2006. The Signal Technical Committee will respond to sponsors' comments during their Summer 2006 meeting. The pedestrian beacon represents devices that this study found to be most effective on high-volume, high-speed roadways.

Recommendation

The research team recommends a continuing dialog with the appropriate NCUTCD technical committees in order to encourage adoption of these recommended revisions to the MUTCD. To change the MUTCD, it may be necessary for such a dialog to continue beyond the duration of this study. Members of the research team have already presented proposed MUTCD revisions, with some elements received favorably and other elements requiring considerably more discussion and debate.

Walking Speed

Summary

Pedestrians have a wide range of needs and abilities. The MUTCD includes a walking speed of 4.0 ft/s (1.2 m/s) for calculating pedestrian clearance intervals for traffic signals. It also includes a comment that, where pedestrians walk more slowly than normal or pedestrians in wheelchairs routinely use the crosswalk, a walking speed of less than 4.0 ft/s (1.2 m/s) should be considered in determining the pedestrian clearance times. Other research studies have identified pedestrian walking speeds ranging from 2.2 to 4.3 ft/s (0.6 to 1.3 m/s). In 2002, the U.S. Access Board used the guidelines prepared by the Public Rights-of-Way Access Advisory Committee and recommended a universal maximum pedestrian walking speed of 3.0 ft/s (0.9 m/s) (*57*).

One of the pedestrian characteristics collected during the field studies was the time for pedestrians to cross to the middle of the street or median and then to the other side of the street. Using the distances being crossed, the walking speeds of the pedestrians were determined. To permit comparisons with other studies, the data were grouped to reflect the following:

- Younger—includes pedestrians between the ages of 13 and 60 and
- Older—includes pedestrians older than 60.

The following conclusions were developed for walking speed:

- The 15th percentile walking speed for younger pedestrians is 3.77 ft/s (1.15 m/s) (sample size of 2,335), and the 15th percentile walking speed for older pedestrians is 3.03 ft/s (0.92 m/s) (sample size of 106).
- The older pedestrian groups (male, female, and both) had 15th percentile walking speeds that differed statistically from the 15th percentile walking speeds of the younger pedestrians.
- Two studies with databases that contain more than 2,000 pedestrian crossings are the 1996 Knoblauch et al. study (*14*) (data collected in 1993) and this TCRP/NCHRP study. The data collected in 2003 for the TCRP/NCHRP study identified a slower walking speed for the younger group—(3.77 ft/s [1.15 m/s] as compared with 4.02 ft/s [1.23 m/s])—than found in the 1993 data collected for the Knoblauch et al. study.
- When both older pedestrians and younger pedestrians are considered using the Knoblauch et al. data (sample size of 4,459), the 15th percentile value of 3.53 ft/s (1.08 m/s) was determined.

Recommendation

Comparing the findings from this TCRP/NCHRP study with previous work resulted in the following recommendations:

- 3.5 ft/s (1.1 m/s) walking speed for general population and
- 3.0 ft/s (0.9 m/s) walking speed for older or less able population.

These values are being considered for the upcoming revision to the MUTCD.

Motorist Compliance

Summary

The research team chose motorist compliance (yielding or stopping where required) as the primary measure of effectiveness for engineering treatments at unsignalized roadway crossings. Motorist compliance data were collected at 42 study sites that included nine different types of pedestrian crossing treatments. In addition to collecting motorist yielding behavior for general population pedestrians, the data collection personnel also staged street crossings to ensure consistency among all sites as well as adequate sample sizes. The research team analyzed motorist compliance thoroughly and used the findings to support development of the *Guidelines for Pedestrian Crossing Treatments*. Conclusions about motorist compliance are as follows:

- The crossing treatment affects motorist compliance. Those treatments that show a red indication to the motorist have a statistically significant different compliance rate from devices that do not show a red indication. These red signal or beacon devices had compliance rates greater than 95 percent and included midblock signals, half signals, and HAWK signal beacons. Nearly all the red signal or beacon treatments evaluated were used on busy, high-speed arterial streets. Pedestrian crossing flags and in-street crossing signs also were effective in prompting motorist yielding, achieving 65 and 87 percent compliance, respectively. However, most of these crossing treatments were installed on lower-volume, two-lane roadways.
- The measured motorist compliance for many crossing treatments varied considerably among sites. For example, treatments in the "active when present" and "enhanced and/or high-visibility" categories have a wide range of compliance rates as shown in Figure 24. In fact, a statistical analysis could find no significant differences between many of the crossing treatments, even though the difference in average compliance rates appeared to be practically significant (30 to 40 percent greater). The research team concluded that other factors (such as, roadway width, speed limit, and street environment) affected compliance rates.
- The number of lanes being crossed influences the effectiveness of the crossing treatment. All but one of the treatments on the two-lane roadways performed at a better than 75-percent compliance rate. On four-lane roadways, compliance ranged from below 30 percent to 100 percent.
- The posted speed limit influences the effectiveness of the crossing treatment. Flags, refuge islands, and high-visibility markings all have higher compliance rates on lower-speed roadways. On a 35-mph (55-km/h) roadway, the best compliance rate observed for a treatment not showing a red indication to the motorist was about 58 percent. Compliance rates for the devices on 25-mph (40-km/h) streets all were above 60 percent. Compliance rates were as low as 15 percent for streets with a 35-mph (55-km/h) speed limit.

Recommendation

The research team recommends the addition of red signal or beacon devices to the engineer's alternative for pedestrian crossings. The study results indicated that all red signal or beacon devices prompted high levels of motorist compliance on high-volume, high-speed streets; however, only a traffic signal is currently recognized in the MUTCD, and the current pedestrian signal warrant is very difficult to meet. Thus, in the current situation, engineers cannot easily use those traffic control devices that appear to be most effective for pedestrians on wide, high-speed streets. As indicated previously in the signal warrant recommendations, the research team recommends the inclusion of a new type of highway traffic signal (a "pedestrian beacon") in the MUTCD. These pedestrian beacons would have different signal operation modes than traditional traffic control signals and would include the red signal or beacon devices that this study found to be most effective on high-volume, high-speed roadways.

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Abbreviations, Acronyms, and Initialisms

HAWK	High-intensity activated crosswalk
HCM	*Highway Capacity Manual*
HSD	Honestly significant difference
HSRC	Highway Safety Research Center
ITE	Institute of Transportation Engineers
LOS	Level of service
MOE	Measure of effectiveness
MUTCD	*Manual on Uniform Traffic Control Devices on Streets and Highways*
NCUTCD	National Committee on Uniform Traffic Control Devices
PDA	Personal digital assistant
RMSE	Root mean square error
SAS	Statistical Analysis Software
SUV	Sport utility vehicle
TTI	Texas Transportation Institute
VCR	Videocassette recorder

APPENDIX A

Guidelines for Pedestrian Crossing Treatments

Introduction

These guidelines provide general recommendations on pedestrian crossing treatments to consider at unsignalized intersections; in all cases, engineering judgment should be used in selecting a specific treatment for installation. The following guidelines build on the recommendations of several studies and focus on unsignalized intersections. They do not apply to school crossings. Considerations (in addition to the procedure provided in these guidelines) should be used where a pedestrian treatment could present an increased safety risk to pedestrians, such as where there is poor sight distance, complex geometrics, or traffic signals.

System of Treatments

The installation of a pedestrian crossing treatment alone does not necessarily result in more vehicles stopping for pedestrians unless that device shows a red indication to the motorist. Therefore, treating a location to improve pedestrian access or safety should include several components. For example, in addition to traffic control devices (TCDs) such as signs or markings, geometric improvements (e.g., refuge island, roadway narrowing, and curb extensions) may be used to shorten the crossing distance (and hence the exposure time for the pedestrian). Traffic calming may be used to slow vehicle speeds near the pedestrian crossing.

Overview of Procedure

Figure A-1 provides an overview of the procedure. Tables A-1 and A-2 list the variables needed for the evaluation and the calculations that are to be performed, respectively.

Step 1: Select Worksheet

Two worksheets are available–a worksheet for speeds of 35 mph (55 km/h) or less and a worksheet for speeds that exceed 35 mph (55 km/h) where the community has a population of less than 10,000 or where a major transit stop exists. The first step is to select the appropriate worksheet. The speeds represent the posted or statutory speed limit or the 85th percentile speed on the major street, whichever is higher. The worksheets available are

- Worksheet 1: 35 mph (55 km/h) or less (see Figure A-2) and
- Worksheet 2: exceeds 35 mph (55 km/h), in communities with less than 10,000 in population, or where a major transit stop exists (see Figure A-3).

Step 2: Check Minimum Pedestrian Volume

The minimum pedestrian volume for a peak-hour evaluation is 20 pedestrians per hour for both directions (14 ped/h if the major road speed exceeds 35 mph [55 km/h]). If fewer pedestrians are crossing the street, then geometric improvements (rather than signs, signals, or markings) such as traffic calming, median refuge islands, and curb extensions, are alternatives that can be considered.

Step 3: Check Signal Warrant

The MUTCD signal warrants are checked in Step 3 to determine whether to consider a signal at the site. The signal warrant procedures recommended in this step (which will be considered as changes to the MUTCD by the National Committee on Uniform Traffic Control Devices) more closely align the Pedestrian Signal Warrant with the current (2003) Peak-Hour Signal Warrant for vehicles (with adjustment made to reflect the counting of pedestrians crossing the major roadway from both approaches rather than only the highest approach as used in the vehicle signal warrant). The worksheets include equations that can determine the minimum required number of crossing pedestrians for a given major-road vehicle volume.

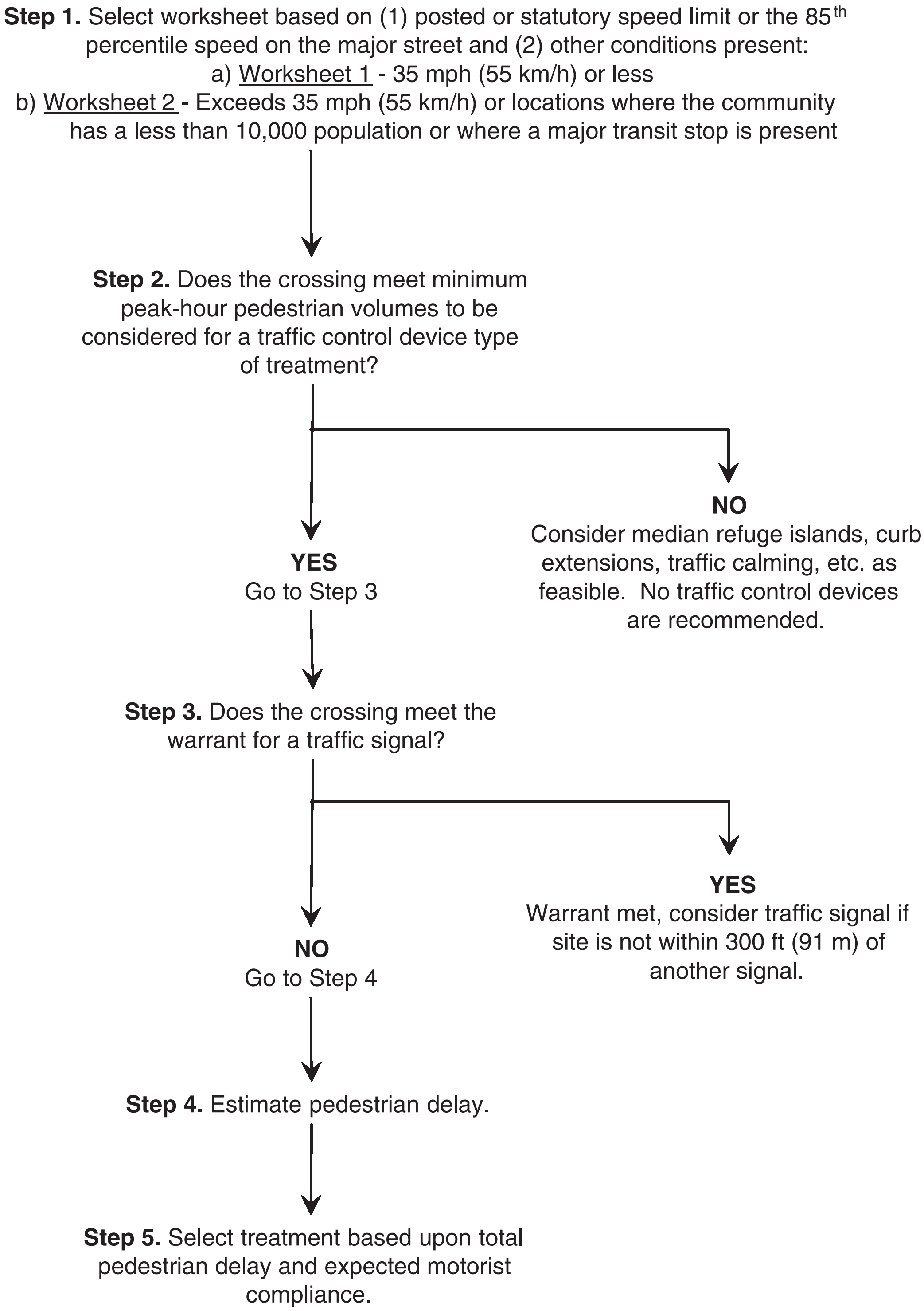

Figure A-1. Flowchart for Guidelines for Pedestrian Crossing Treatments.

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Table A-1. Input Variables for Guidelines for Pedestrian Crossing Treatment.

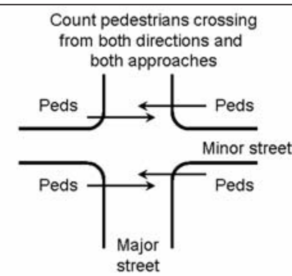
INPUT VARIABLES	TERM	DISCUSSION
ROAD CHARACTERISTICS		
Speed on the major street (mph)	S_{maj}	Use the major road posted or statutory speed limit for the facilities or, if available, the 85th percentile speed to determine which worksheet is applicable. Worksheet 1 is used when the speed is 35 mph (55 km/h) or less, while Worksheet 2 is used when the speed exceeds 35 mph (55 km/h).
Pedestrian **crossing distance** (ft)	L	Pedestrian crossing distance represents the distance that a pedestrian would need to cross before reaching either the far curb or a median refuge island. The distance would be between the near and far curbs if a painted or raised median refuge island is not present, or to the median refuge island if the island is present. Note if a parking stall is present, its width should be included in the crossing distance measurement. Crossing distance rather than number of lanes was selected for the procedure so that the extra time needed by a pedestrian to cross bike lanes, two-way left-turn lanes, wide lanes, etc. could be considered.
COUNTS		
Peak-hour **pedestrian volume** crossing major roadway (ped/h)	V_p	Pedestrian volume is the number of pedestrians crossing the major roadway in a peak hour. The count includes all pedestrian crossings of the major roadway at the location. 
Major road peak hour **vehicle volume** (veh/h)	V_{maj-s} V_{maj-d}	Vehicle volume represents the number of vehicles and bicycles on both approaches of the major road during a peak hour. If a painted or raised median refuge island is present of sufficient size to store pedestrians (minimum of 6 ft [1.8 m] wide), then consider the volume on each approach individually. In the signal warrant calculations, use the volume on both approaches (V_{maj-s}). For the delay calculations, the volume (V_{maj-d}) would reflect either both approaches if a refuge island is not present or each approach individually if a refuge island is present.
LOCAL PARAMETERS		
Motorist **compliance** for region (high or low)	Comp	Compliance reflects the typical behavior of motorists for the site. If motorists tend to stop for a pedestrian attempting to cross at an uncontrolled location, then compliance is “high.” If motorists rarely stop for a crossing pedestrian, then compliance is “low.”
Pedestrian **walking speed** (ft/s)	S_p	Walking speed represents the speed of the crossing pedestrians. Recent research has suggested walking speeds of 3.5 ft/s (1.1 m/s) for the general population and 3.0 ft/s (0.9 m/s) for the older population. If calculating for a site, determine the 15th percentile value of those using the crossing.
Pedestrian **start-up** time and end clearance time (s)	t_s	Start-up time is used in the calculation of the critical gap. A value of 3 s is suggested in the *Highway Capacity Manual.*

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Table A-2. Calculations for Guidelines for Pedestrian Crossing Treatment.

CALCs	TERM	DISCUSSION
Signal warrant check (ped/h)	SC	Regression equations were determined for the plots shown in the 2003 *MUTCD* Figures 4C-3 and 4C-4. These equations can calculate the minimum number of vehicles that would be needed at the given major road volume to meet the signal warrant. The recommendation made in 2006 to the National Committee on Uniform Traffic Control Devices is that the vehicles signal warrants values for crossing two lanes be used as the pedestrian signal warrant values. Because the pedestrian signal warrant is to reflect total pedestrian crossings rather than just the number of pedestrians on the higher approach, the vehicle signal warrant values should be divided by 0.75 to reflect an assumed directional distribution split of 75/25. Different equations are provided for low-speed and high-speed conditions. The worksheets provide instructions on checking the peak hour. Both the peak vehicle hour and the peak pedestrian hour may need to be checked.
Critical gap (s)	T_c	Critical gap is the time in seconds below which a pedestrian will not attempt to begin crossing the street. For a single pedestrian, critical gap (t_c) can be computed using Equation 18-17 of the *2000 Highway Capacity Manual.* The equation includes consideration of the pedestrian walking speed (S_p), crossing distance (L), and start-up and end clearance times (t_s). $$t_c = (L/S_p) + t_s$$
Major road flow rate (veh/s)	v	Flow rate is a measure of the number of vehicles per second (v). For high-speed conditions, the number of vehicles is adjusted by dividing by 0.7. Flow rate is determined by: Low speed: $v = V_{maj\text{-}p}/3600$ high speed: $v = (V_{maj\text{-}p}/0.7)/3600$ It is based on the major road volume ($V_{maj\text{-}d}$), which is the total of both approaches (or the approach being crossed if median refuge island is present) during the peak hour (veh/h).
Average pedestrian delay (s/person)	d_p	The *2000 Highway Capacity Manual* includes Equation 18-21 that can be used to determine the average delay per pedestrian at an unsignalized intersection crossing (s/person). $$d_p = \frac{1}{v}\left(e^{vt_c} - vt_c - 1\right)$$ It depends upon critical gap (t_c), the vehicular flow rate of the crossing (v), and the mean vehicle headway.
Total pedestrian delay (ped-h)	D_p	Total pedestrian delay (D_p) uses the average pedestrian delay (d_p) and multiplies that value by the number of pedestrians (V_p) to determine the total pedestrian delay for the approach. $$D_p = (d_p \times V_p)/3{,}600$$

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WORKSHEET 1: PEAK-HOUR, 35 MPH (55 KM/H) OR LESS

Analyst and Site Information		
Analyst: Analysis Date: Data Collection Date:	Major Street: Minor Street or Location: Peak Hour:	
Step 1: Select worksheet (speed reflects posted or statutory speed limit or 85th percentile speed on the major street): a) Worksheet 1 – 35 mph (55 km/h) or less b) Worksheet 2 – exceeds 35 mph (55 km/h), communities with less than 10,000, or where major transit stop exists		
Step 2: Does the crossing meet minimum pedestrian volumes to be considered for a TCD type of treatment?		
Peak-hour pedestrian volume (ped/h), V_p	*2a*	
If *2a* ≥ 20 ped/h, then go to Step 3.		
If *2a* < 20 ped/h, then consider median refuge islands, curb extensions, traffic calming, etc. as feasible.		
Step 3: Does the crossing meet the pedestrian volume warrant for a traffic signal?		
Major road volume, total of both approaches during peak hour (veh/h), $V_{maj\text{-}s}$	*3a*	
Minimum signal warrant volume for peak hour (use *3a* for $V_{maj\text{-}s}$), SC $SC = (0.00021\ V_{maj\text{-}s}^2 - 0.74072\ V_{maj\text{-}s} + 734.125)/0.75$ OR $[(0.00021\ 3a^2 - 0.74072\ 3a + 734.125)/0.75]$	*3b*	
If *3b* < 133, then enter 133. If *3b* ≥ 133, then enter *3b*.	*3c*	
If 15th percentile crossing speed of pedestrians is less than 3.5 ft/s (1.1 m/s), then reduce *3c* by up to 50 percent; otherwise enter *3c.*	*3d*	
If *2a* ≥ *3d,* then the warrant has been met and a traffic signal should be considered if not within 300 ft (91 m) of another traffic signal. Otherwise, the warrant has not been met. Go to Step 4.		
Step 4: Estimate pedestrian delay.		
Pedestrian crossing distance, curb to curb (ft), L	*4a*	
Pedestrian walking speed (ft/s), S_p	*4b*	
Pedestrian start-up time and end clearance time (s), t_s	*4c*	
Critical gap required for crossing pedestrian (s), $t_c = (L/S_p) + t_s$ OR $[(4a/4b) + 4c)]$	*4d*	
Major road volume, total both approaches or approach being crossed if median refuge island is present during peak hour (veh/h), $V_{maj\text{-}d}$	*4e*	
Major road flow rate (veh/s), $v = V_{maj\text{-}d}/3600$ OR $[4e/3600]$	*4f*	
Average pedestrian delay (s/person), $d_p = (e^{v\,tc} - v\,t_c - 1)/v$ OR $[(e^{4f \times 4d} - 4f \times 4d - 1)/4f]$	*4g*	
Total pedestrian delay (h), $D_p = (d_p \times V_p)/3{,}600$ OR $[(4g \times 2a)/3600]$ (this is estimated delay for all pedestrians crossing the major roadway without a crossing treatment – assumes 0% compliance). This calculated value can be replaced with the actual total pedestrian delay measured at the site.	*4h*	
Step 5: Select treatment based upon total pedestrian delay and expected motorist compliance.		
Expected motorist compliance at pedestrian crossings in region, Comp = high or low	*5*a	

Total Pedestrian Delay, D_p (from *4h*) and Motorist Compliance, Comp (from *5a*)	Treatment Category (see Descriptions of Sample Treatments for examples)
$D_p \geq 21.3$ h (Comp = high or low) OR $5.3\text{ h} \leq D_p < 21.3$ h and Comp = low	RED
$1.3\text{ h} \leq D_p < 5.3$ h (Comp = high or low) OR $5.3\text{ h} \leq D_p < 21.3$ h and Comp = high	ACTIVE OR ENHANCED
$D_p < 1.3$ h (Comp = high or low)	CROSSWALK

Figure A-2. Worksheet 1.

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WORKSHEET 2: PEAK-HOUR, EXCEEDS 35 MPH (55 KM/H)

Analyst and Site Information

Analyst: Analysis Date: Data Collection Date:	Major Street: Minor Street or Location: Peak Hour:

Step 1: Select worksheet (speed reflects posted or statutory speed limit or 85th percentile speed on the major street):
a) Worksheet 1 – 35 mph (55 km/h) or less
b) Worksheet 2 – exceeds 35 mph (55 km/h), communities with less than 10,000, or where major transit stop exists

Step 2: Does the crossing meet minimum pedestrian volumes to be considered for a TCD type of treatment?

Peak-hour pedestrian volume (ped/h), V_p	*2a*	
If *2a* ≥ 14 ped/h, then go to Step 3.		
If *2a* < 14 ped/h, then consider median refuge islands, curb extensions, traffic calming, etc. as feasible.		

Step 3: Does the crossing meet the pedestrian volume warrant for a traffic signal?

Major road volume, total of both approaches during peak hour (veh/h), $V_{maj\text{-}s}$	*3a*	
Minimum signal warrant volume for peak hour (use 3*a* for $V_{maj\text{-}s}$), SC $SC = (0.00035\, V_{maj\text{-}s}^2 - 0.80083\, V_{maj\text{-}s} + 529.197)/0.75$ OR $[(0.00035\, 3a^2 - 0.80083\, 3a + 529.197)/0.75]$	*3b*	
If *3b* < 93, then enter 93. If *3b* ≥ 93, then enter *3b*.	*3c*	
If 15th percentile crossing speed of pedestrians is less than 3.5 ft/s (1.1 m/s), then reduce *3c* by up to 50 percent; otherwise enter *3c.*	*3d*	
If *2a* ≥ *3d,* then the warrant has been met and a traffic signal should be considered if not within 300 ft (91 m) of another traffic signal. Otherwise, the warrant has not been met. Go to Step 4.		

Step 4: Estimate pedestrian delay.

Pedestrian crossing distance, curb to curb (ft), L	*4a*	
Pedestrian walking speed (ft/s), S_p	*4b*	
Pedestrian start-up time and end clearance time (s), t_s	*4c*	
Critical gap required for crossing pedestrian (s), $t_c = (L/S_p) + t_s$ OR $[(4a/4b) + 4c)]$	*4d*	
Major road volume, total both approaches or approach being crossed if median refuge island is present during peak hour (veh/h), $V_{maj\text{-}d}$	*4e*	
Major road flow rate (veh/s), $v = (V_{maj\text{-}d}/0.7)/3600$ OR $[(4e/0.7)/3600]$	*4f*	
Average pedestrian delay (s/person), $d_p = (e^{v\,t_c} - v\,t_c - 1)\,/\,v$ OR $[\,(e^{4f \times 4d} - 4f \times 4d - 1)\,/\,4f\,]$	*4g*	
Total pedestrian delay (h), $D_p = (d_p \times V_p)/3{,}600$ OR $[(4g \times 2a)/3600]$ (this is estimated delay for all pedestrians crossing the major roadway without a crossing treatment – assumes 0% compliance). This calculated value can be replaced with the actual total pedestrian delay measured at the site.	*4h*	

Step 5: Select treatment based upon total pedestrian delay and expected motorist compliance.

Expected motorist compliance at pedestrian crossings in region, Comp = high or low	*5a*	

Total Pedestrian Delay, D_p (from *4h*) and Motorist Compliance, Comp (from *5a*)	**Treatment Category** (see Descriptions of Sample Treatments for examples)
$D_p \geq 21.3$ h (Comp = high or low) OR $5.3 \text{ h} \leq D_p < 21.3$ h and Comp = low	RED
$D_p < 5.3$ h (Comp = high or low) OR $5.3 \text{ h} \leq D_p < 21.3$ h and Comp = high	ACTIVE OR ENHANCED

Figure A-3. Worksheet 2.

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Step 4: Estimate Approach Pedestrian Delay

The average pedestrian delay equation from the *2000 Highway Capacity Manual* is used to determine the approach pedestrian delay.

Step 5: Select Appropriate Treatment

The total pedestrian delay along with the expected compliance is used to determine the treatment category to consider for the site.

Example Using Guidelines

Known

Citizens have requested a pedestrian treatment at the 2700 block crossing of Elm Street. Known characteristics of the site include

- Four-lane road with no pedestrian refuge median;
- 56 ft (17 m) crossing distance;
- 35 mph (55 km/h) speed limit;
- During the peak pedestrian hour, 50 pedestrians counted when the major-road volume was 1,000 veh/h;
- During the peak vehicle hour, 20 pedestrians counted when the major-road volume was 1,500 veh/h; and
- Motorists observed stopping for pedestrians, showing a "high" compliance.

The following assumptions were made:

- Walking speed is 3.5 ft/s (1.1 m/s) and
- Start-up time is 3 seconds.

Calculations

Figure A-1 provides an overview of the procedure. Tables A-1 and A-2 list the variables needed for the evaluation and the calculations that are to be performed, respectively. The following are the procedures for this example:

- **Step 1: Select Worksheet**. Worksheet 1 is the applicable worksheet for a speed limit of 35 mph (55 km/h). Figure A-4 shows the worksheet with appropriate values for the example. Given that the assumed walking speed and the crosswalk length match the values used to generate one of the figures included in the guidelines, that plot can be used rather than using Worksheet 1 to determine the suggested pedestrian treatment. Figure A-5 shows the plot.
- **Step 2: Check Minimum Pedestrian Volume**. The next step is to determine if a minimum number of pedestrians are present at the site. Because more than 20 pedestrians are crossing the roadway during the peak hour, some form of a pedestrian treatment is suggested.
- **Step 3: Check Signal Warrant.** The minimum number of pedestrians needed on the minor-road approach crossing a four-lane roadway with 1,000 vehicles in the peak hour is 271. The number of crossing pedestrians (50) is less than the 271 value; therefore, a signal is not warranted under the pedestrian volume warrant. Checking the peak vehicle hour provides the same result: a signal is not warranted under the pedestrian volume warrant.
- **Step 4: Estimate Approach Pedestrian Delay**. The average pedestrian delay equation was used to determine the total pedestrian delay. A total pedestrian delay value of 9.8 ped-h was calculated.
- **Step 5: Select Appropriate Treatment**. The motorist compliance observed at the site is "high." With a total pedestrian delay value of 9.8 ped-h and a motorist compliance of high, the worksheet indicates that an "enhanced/active" device should be considered. Figure A-5 shows the solution using the major roadway volume of 1,000 veh/h and the pedestrian volume of 50. The intersection of these two lines (see circle in Figure A-5) results in the same finding: "enhanced/active" device. The following section lists suggested treatments within the categories.

Descriptions of Sample Treatments

The treatments included in these guidelines are divided into broad classes of elements and devices. Elements are used either uniquely or to supplement a device. A device represents the primary component of a pedestrian treatment.

The **elements** discussed here have been divided into two categories:

- **Supplemental Signs and Markings.** This category is composed of applications of signs and markings beyond the standard crosswalk markings and pedestrian crossing signs discussed in the "Crosswalk" category of devices below. Items in this category include advance stop lines and advance signing.
- **Geometric Elements.** This category pertains to crosswalk elements that are permanent installations but are not signs, markings, or devices. These are elements installed based on engineering judgment rather than a warrant and include items such as median refuge islands and curb extensions.

The **devices** discussed here have been divided into five categories:

- **Crosswalk.** This category encompasses standard crosswalk markings and pedestrian crossing signs, as opposed to unmarked crossings.

<table>
<tr><td colspan="3">WORKSHEET 1: PEAK-HOUR, 35 MPH (55 KM/H) OR LESS</td></tr>
<tr><td colspan="3">Analyst and Site Information</td></tr>
<tr><td colspan="3">Analyst: Maria
Analysis Date: 1/19/06
Data Collection Date: 1/19/06
Major Street: Elm
Minor Street or Location: 2700 Block
Peak Hour: 5 to 6 pm</td></tr>
<tr><td colspan="3">Step 1: Select worksheet (speed reflects posted or statutory speed limit or 85th percentile speed on the major street):
a) Worksheet 1 – 35 mph (55 km/h) or less
b) Worksheet 2 – exceeds 35 mph (55 km/h), communities with less than 10,000, or where major transit stop exists</td></tr>
<tr><td colspan="3">Step 2: Does the crossing meet minimum pedestrian volumes to be considered for a TCD type of treatment?</td></tr>
<tr><td>Peak-hour pedestrian volume (ped/h), V_p</td><td>2a</td><td>50</td></tr>
<tr><td colspan="3">If 2a ≥ 20 ped/h, then go to Step 3.</td></tr>
<tr><td colspan="3">If 2a < 20 ped/h, then consider median refuge islands, curb extensions, traffic calming, etc. as feasible.</td></tr>
<tr><td colspan="3">Step 3: Does the crossing meet the pedestrian volume warrant for a traffic signal?</td></tr>
<tr><td>Major road volume, total of both approaches during peak hour (veh/h), $V_{maj\text{-}s}$</td><td>3a</td><td>1000</td></tr>
<tr><td>Minimum signal warrant volume for peak hour (use 3a for $V_{maj\text{-}s}$), SC
$SC = (0.00021\, V_{maj\text{-}s}^2 - 0.74072\, V_{maj\text{-}s} + 734.125)/0.75$
OR $[(0.00021\, 3a^2 - 0.74072\, 3a + 734.125)/0.75]$</td><td>3b</td><td>271</td></tr>
<tr><td>If 3b < 133, then enter 133. If 3b ≥ 133, then enter 3b.</td><td>3c</td><td>271</td></tr>
<tr><td>If 15th percentile crossing speed of pedestrians is less than 3.5 ft/s (1.1 m/s), then reduce 3c by up to 50 percent; otherwise enter 3c.</td><td>3d</td><td>271</td></tr>
<tr><td colspan="3">If 2a ≥ 3d, then the warrant has been met and a traffic signal should be considered if not within 300 ft (91 m) of another traffic signal. Otherwise, the warrant has not been met. Go to Step 4.</td></tr>
<tr><td colspan="3">Step 4: Estimate pedestrian delay.</td></tr>
<tr><td>Pedestrian crossing distance, curb to curb (ft), L</td><td>4a</td><td>56</td></tr>
<tr><td>Pedestrian walking speed (ft/s), S_p</td><td>4b</td><td>3.5</td></tr>
<tr><td>Pedestrian start-up time and end clearance time (s), t_s</td><td>4c</td><td>3</td></tr>
<tr><td>Critical gap required for crossing pedestrian (s), $t_c = (L/S_p) + t_s$ OR $[(4a/4b) + 4c)]$</td><td>4d</td><td>19</td></tr>
<tr><td>Major road volume, total both approaches or approach being crossed if median refuge island is present during peak hour (veh/h), $V_{maj\text{-}d}$</td><td>4e</td><td>1000</td></tr>
<tr><td>Major road flow rate (veh/s), $v = V_{maj\text{-}d}/3600$ OR $[4e/3600]$</td><td>4f</td><td>0.28</td></tr>
<tr><td>Average pedestrian delay (s/person), $d_p = (e^{v\,t_c} - v\,t_c - 1)/v$ OR $[(e^{4f \times 4d} - 4f \times 4d - 1)/4f]$</td><td>4g</td><td>707</td></tr>
<tr><td>Total pedestrian delay (h), $D_p = (d_p \times V_p)/3{,}600$ OR $[(4g \times 2a)/3600]$
(this is estimated delay for all pedestrians crossing the major roadway without a crossing treatment – assumes 0% compliance). This calculated value can be replaced with the actual total pedestrian delay measured at the site.</td><td>4h</td><td>9.8</td></tr>
<tr><td colspan="3">Step 5: Select treatment based upon total pedestrian delay and expected motorist compliance.</td></tr>
<tr><td>Expected motorist compliance at pedestrian crossings in region, Comp = high or low</td><td>5a</td><td>high</td></tr>
<tr><td>Total Pedestrian Delay, D_p (from 4h) and Motorist Compliance, Comp (from 5a)</td><td colspan="2">Treatment Category
(see Descriptions of Sample Treatments for examples)</td></tr>
<tr><td>$D_p \geq 21.3$ h (Comp = high or low)
OR
$5.3\text{ h} \leq D_p < 21.3$ h and Comp = low</td><td colspan="2">RED</td></tr>
<tr><td>$1.3\text{ h} \leq D_p < 5.3$ h (Comp = high or low)
OR
$5.3\text{ h} \leq D_p < 21.3$ h and Comp = high</td><td colspan="2">ACTIVE
OR
ENHANCED</td></tr>
<tr><td>$D_p < 1.3$ h (Comp = high or low)</td><td colspan="2">CROSSWALK</td></tr>
</table>

Figure A-4. Example Problem – Crossing at Elm Street.

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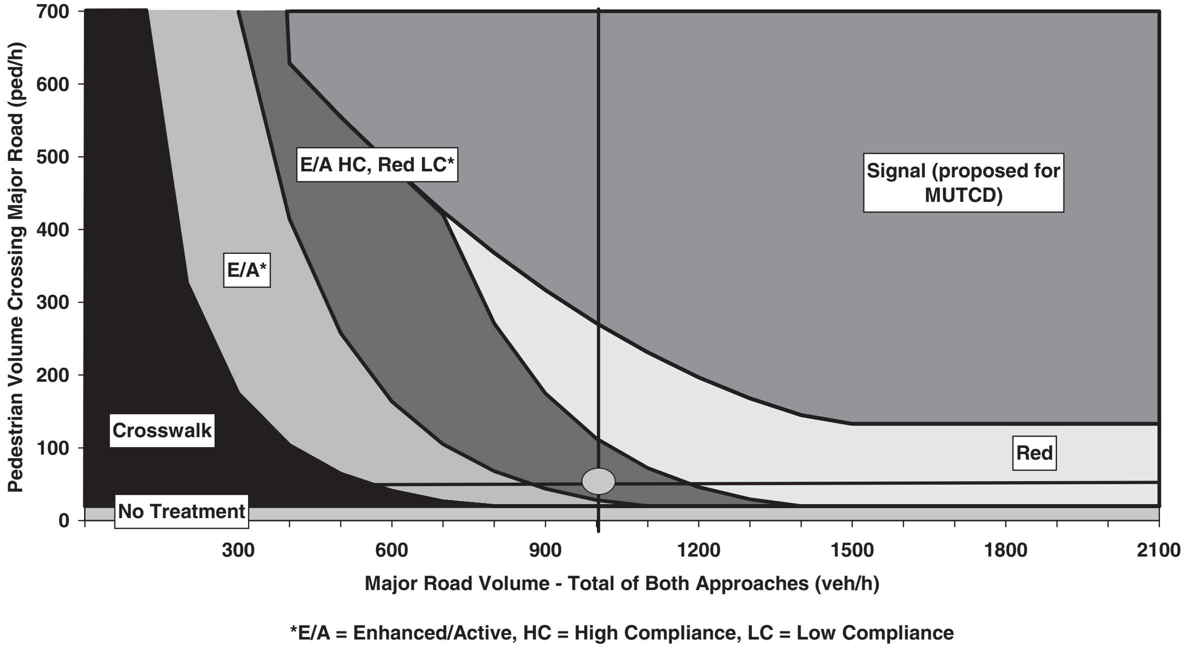

Figure A-5. Graphical Solution to Example Problem.

- **Enhanced.** This category includes those devices that enhance the visibility of the crossing location and pedestrians waiting to cross. Warning signs, markings, or beacons in this category are present or active at the crossing location at all times.
- **Active.** Also called "active when present," this category includes those devices designed to display a warning only when pedestrians are present or crossing the street.
- **Red.** This category includes those devices that display a circular red indication (signal or beacon) to motorists at the pedestrian location.
- **Signal.** This category pertains to traffic control signals.

Synopses of Treatments

Synopses of selected pedestrian crossing treatments are presented in Table A-3.

Categories of Treatments

Tables A-4 through A-20 summarize information on examples of selected pedestrian crossing treatments. These summaries reflect the more common treatments being used and do not include every device or treatment available. The following summaries are intended to provide general descriptions of pedestrian crossing treatments that may be installed at intersections and/or midblock crossings; in all cases, engineering judgment should be used in selecting a specific treatment for installation.

The summaries are based on observations of installed treatments and discussions with traffic engineers who have used or considered using one or more of the components. This selection of pedestrian crossing treatments is not necessarily an all-inclusive list, nor is it intended to be. As technology changes and as more jurisdictions study ways to address the issue of pedestrian crossings, other treatments will likely be discussed and/or tested.

Additional Sources of Information on Pedestrian Treatments

Additional information on treatments is available from the following references:

- *Manual on Uniform Traffic Control Devices for Streets and Highways*. U.S. DOT, FHWA, Washington, D.C., 2003. Available online at http://mutcd.fhwa.dot.gov/, accessed June 2, 2005.
- *A Policy on Geometric Design of Highways and Streets* (called the Green Book). AASHTO, Washington, D.C., 2003.
- *Guide for the Planning, Design, and Operation of Pedestrian Facilities* (called the Ped Guide). AASHTO, Washington, D.C., July 2004.
- Zegeer, C. V., C. Seiderman, P. Lagerwey, M. Cynecki, M. Ronkin, and R. Schneider. *Pedestrian Facilities User Guide – Providing Safety and Mobility.* FHWA-RD-01-102, FHWA, Washington, D.C., March 2002.

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Table A-3. Synopsis of Crossing Treatments.

Treatment	Characteristics
Advance Signing	■ Provides additional notification to drivers that a crosswalk is near
Advance Stop Line and Sign	■ Vehicle stop line is moved back from the crosswalk
Median Refuge Island	■ Accessible pedestrian path within a raised median
Raised Crosswalk	■ Crosswalk surface elevated above driving lanes
Curb Extension	■ Curb adjacent to crosswalk lengthened by the width of the parking lane
Roadway Narrowing	■ Reduced lane widths and/or number of vehicle lanes
Markings and Crossing Signs	■ Standard crosswalk markings and pedestrian crossing signs ■ Subject to *MUTCD* requirements
In-Street Pedestrian Crossing Signs	■ Regulatory signs placed in the street ■ Subject to *MUTCD* requirements
High-Visibility Signs and Markings	■ Warning devices placed at or in advance of the pedestrian crossing ■ Subject to *MUTCD* requirements
In-Roadway Warning Lights	■ Amber flashing lights mounted flush to the pavement surface at the crossing location
Pedestrian Crossing Flags	■ Square flags on a stick carried by pedestrians ■ Stored in sign-mounted holders on both sides of the street ■ Experimental; not currently in the *MUTCD*
Overhead Flashing Amber Beacons	■ Mounted on mast arms that extend over the roadway or on signposts at the roadside ■ Pedestrian activated ■ Subject to *MUTCD* requirements
Pedestrian Crosswalk Signal	■ Standard traffic signal at a pedestrian crosswalk ■ Pedestrian activated
Half Signal	■ Standard traffic signal on major road ■ Experimental; not currently in the *MUTCD*
HAWK Beacon Signal	■ Combination of a beacon flasher and a traffic control signal ■ Dwells in a dark mode; pedestrian activated ■ Used exclusively in Tucson and Pima County, Arizona ■ Experimental; not currently in the *MUTCD*
Pedestrian Beacon	■ Proposed device; not currently in the *MUTCD* ■ Pedestrian activated
Traffic Signal	■ Standard traffic signal at an intersection or midblock location ■ Pedestrian phase typically activated by a pushbutton ■ Subject to *MUTCD* requirements

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Table A-4. Supplemental Signs and Markings: Advance Signing.

Advance Signing

Advance signing is used to provide additional notification to drivers that a crosswalk is near and pedestrians may be crossing the roadway. Advance signing may be used in a wide variety of situations (intersections, midblock crossings, school-related crosswalks, two-lane or multi-lane roads, and divided or undivided roads), but they are particularly useful at locations where a crosswalk might be unexpected by approaching drivers.

Advance Sign with Advisory Speed Plaque for School Crosswalk

Advance Sign for Midblock Crossing

- ***MUTCD* Description:** Non-vehicular signs may be used to alert road users in advance of locations where unexpected entries into the roadway or shared use of the roadway by pedestrians, animals, and other crossing activities might occur. When used in advance of a crossing, non-vehicular warning signs may be supplemented with supplemental plaques with the legend AHEAD, XX FEET, or NEXT XX MILES to provide advance notice to road users of crossing activity. Pedestrian, Bicycle, and School signs and their related supplemental plaques may have a fluorescent yellow-green background with a black legend and border.

- ***MUTCD* Guidance:** When a fluorescent yellow-green background is used, a systematic approach featuring one background color within a zone or area should be used. The mixing of standard yellow and fluorescent yellow-green backgrounds within a selected site area should be avoided. Non-vehicular signs should be used only at locations where the crossing activity is unexpected or at locations not readily apparent.

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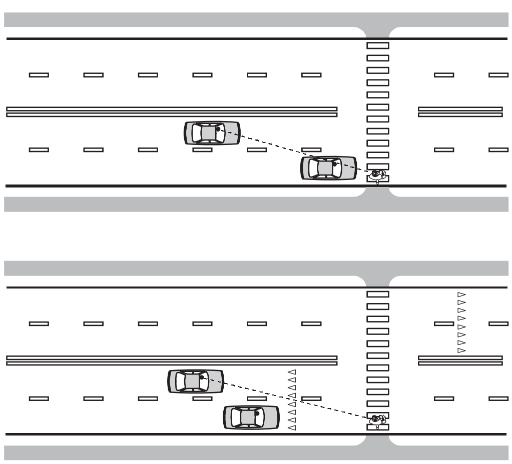
Table A-5. Supplemental Signs and Markings: Advance Stop Line and Sign.

Advance Stop Line and Sign

At midblock crossings and signalized or stop-controlled approaches to intersections, the vehicle stop line can be moved farther back from the pedestrian crosswalk for an improved factor of safety and for improved visibility of pedestrians. Advance stop lines are also applicable for non-signalized crosswalks on multi-lane roads to ensure that drivers in all lanes have a clear view of a crossing pedestrian.

Advance Stop Line on Multi-lane Approach to Marked Crosswalk



Example of Increased Visibility to Pedestrians from Advance Yield Line

- **FHWA *Ped Facilities Users Guide* Description:** Advance stop lines allow pedestrians and drivers to have a clearer view of each other and more time in which to assess intentions. The effectiveness of this tool depends upon whether motorists are likely to obey the stop line, which varies. In some places, the stop line has been moved back by 15 to 30 ft (4.6 to 9.1 m) relative to the marked crosswalk with considerable safety benefits for pedestrians.

- ***MUTCD* Guidance:** If used, stop and yield lines should be placed a minimum of 4 ft (1.2 m) in advance of the nearest crosswalk line at controlled intersections. If used at an unsignalized midblock crosswalk, yield lines should be placed adjacent to the Yield Here to Pedestrian sign located 20 to 50 ft (6.1 to 15 m) in advance of the nearest crosswalk line, and parking should be prohibited in the area between the yield line and the crosswalk.

R1-5

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Table A-6. Geometric Element: Pedestrian Median Refuge Islands.

Pedestrian Median Refuge Islands

Pedestrian median refuge islands are a roadway design treatment that permits pedestrians to cross one direction of street traffic at a time. Median refuge islands are typically raised above the roadway surface with an accessible pedestrian path. In some cases they are offset to direct the view of crossing pedestrians at the second direction of street traffic. Two-way left-turn lanes and other median treatments that vehicles routinely enter are not considered appropriate refuge for pedestrians.

Pedestrian Median Refuge Island

Wide Median Refuge Island with Landscaping

- **AASHTO *Green Book* Description:** A pedestrian median refuge island is near a crosswalk or bicycle path. Raised-curb corner islands and center divisional or channelizing islands can be used as refuge areas. Refuge islands for bicyclists and pedestrians crossing a wide street, for loading or unloading transit riders, or for wheelchair ramps are used primarily in urban areas.

- ***Green Book* Guidance:** Refuge islands used by bicyclists should be at least 6-ft (1.8-m) wide. Pedestrians and bicyclists should have a clear path through the island with no obstructions such as poles or sign posts.

- **AASHTO *Ped Guide* Guidance:** Medians and crossing islands should be at least 6-ft (1.8-m) wide so that more than one pedestrian can wait and so that 2-ft (0.61-m) detectable warnings can be provided at both sides of the island. Where practical, a width of 8-ft (2.4-m) may be provided to accommodate wheeled devices and groups of pedestrians and to provide a pedestrian storage area separated by at least 2-ft (0.6-m) from the face of the curb.

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Table A-7. Geometric Element: Raised Crosswalks.

Raised Crosswalks

Raised crosswalks are a supplemental element to standard crosswalks. The crosswalk is installed on a surface that is elevated above the surface of the adjacent driving lanes. The elevated surface attracts drivers' attention and is intended to encourage lower speeds by providing a visual and tactile feedback when approaching the crosswalk. Raised crosswalks may be a constant height for the entire width of the roadway, or they may have gaps to allow bicycles and motorcycles to pass through.

Raised Crosswalks with Supplemental Sign and Flashing Beacon

Advance Warning Sign for Raised Crosswalk (Not in 2003 *MUTCD*)

- **AASHTO *Ped Guide* Description:** Raised crosswalks (or speed tables) are appropriate at midblock locations on local streets, collector roads, and other locations such as airport drop-off and pick-up zones, shopping centers, and campuses. Raised crosswalks can make sidewalks accessible without adding curb ramps.

- **AASHTO *Ped Guide* Guidance:** Raised crosswalks function as an extension of the sidewalk and allow pedestrians to cross at close to a constant grade, without the need for curb ramps. They are suitable only on low-speed local streets that are not emergency routes. Raised crossings should have a parabolic approach transition, raising the vehicle at least 3-to-6-in (152-mm) above the normal pavement grade. The flat section of the crossing table should be 10-to-12-ft (3.7-m) wide. They should be highly visible and striped as a midblock crossing. The approach should be clearly marked or constructed of a contrasting pavement design with a smooth and stable surface. Detectible warnings should be placed at the curb lines.

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Table A-8. Geometric Element: Curb Extensions.

Curb Extensions

Curb extensions provide pedestrian refuge and shorten the crossing distance at crosswalks where they are installed. They can also improve the sight distance and sight lines for both pedestrians and motorists. They prevent parked cars from encroaching into the crosswalk area, and they can create adequate space for curb ramps and landings on narrow sidewalks. Curb extensions are used adjacent to on-street parking, where the curb is extended to a distance approximately equal to the width of the parking lane. They can be used at a crossing on one or both sides of the street.

Curb Extension with Bus Stop (Also Known as a Bus Bulb) at Midblock Crossing

Curb Extension at Intersection

- **AASHTO *Ped Guide* Description:** Curb extensions reduce the crossing distance for pedestrians, improve sight distance for all users, and slow down traffic. They narrow the street to provide a visual distinction to oncoming motorists that they are approaching a crossing.

- **AASHTO *Ped Guide* Guidance:** Curb extensions extend approximately 6 ft (1.8 m) from the curb. When used on arterials, the remaining width should be adequate for both motor vehicles and bicycles. They may not be needed or desirable on every leg of an intersection if the street is narrow, parking is not permitted, or the extension would interfere with a bicycle lane or the ability of design vehicles to make a right turn.

- **TCRP Report 65 *Evaluation of Bus Bulbs* Guidance:** Curb extensions with a bus stop are appropriate where there is on-street parking, high levels of pedestrian activity and/or bus patronage at the bus stop, lower operating speed, and two travel lanes per direction (that allow passing of stopped buses). Conditions that could limit their use include complex drainage patterns, high bicycle traffic, and two-lane streets.

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Table A-9. Geometric Element: Roadway Narrowing.

Roadway Narrowing

Roadway narrowing can be used for lowering vehicle speeds and increasing safety in the areas around pedestrian crossings, as well as redistributing space to other users. Narrowing can occur at selected locations along a corridor or over the entire corridor itself. The physical and visual characteristics of the roadway narrowing encourage drivers to reduce their speeds, which can facilitate pedestrian traffic in the area.

Roadway Narrowing on Suburban Collector

- **FHWA *Ped Facilities Users Guide* Description:** Roadway narrowing can be achieved in several different ways: a) reduce lane width and stripe the excess with a bicycle lane or shoulder, b) remove travel lanes, or c) physically narrow the street by extending sidewalks and landscape areas. This can reduce vehicle speeds along a roadway section and enhance movement and safety for pedestrians. Bicycle travel will also be enhanced and bicyclist safety improved when bicycle lanes are added.

- Bicyclists must be safely accommodated. Bike lanes or wide curb lanes are needed if vehicle volumes are high. Road narrowing must also consider truck volumes and access for school buses and emergency services. Before utilizing roadway narrowing, users should evaluate whether narrowing may encourage traffic to divert to other local streets in the neighborhood.

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Table A-10. Crosswalk: Markings and Crossing Signs.

Markings and Crossing Signs

Standard crosswalk markings and pedestrian crossing signs are described in the 2003 *Manual of Uniform Traffic Control Devices*, in Section 3B.17 and Section 2C.41, respectively.

Markings provide guidance for pedestrians who are crossing roadways by defining and delineating paths on approaches to and within signalized intersections, and on approaches to other intersections where traffic stops. They also alert road users of a pedestrian crossing point across roadways not controlled by signals or Stop signs. At non-intersection locations, markings legally establish the crosswalk. Specific guidance on the use of marked crosswalks is provided in FHWA-RD-01-075. These FHWA guidelines may be used as a supplement to the guidelines for marked crosswalks presented here.

Pedestrian crossing signs (W11-2) may be used to alert road users in advance of locations where unexpected entries into the roadway or shared use of the roadway by pedestrians may occur.

W11-2 Crossing Sign with Crosswalk Markings

- ***MUTCD* Markings Standard:** When crosswalk lines are used, they shall consist of solid white lines that shall not be less than 6 in nor greater than 24 in wide.

- ***MUTCD* Markings Guidance:** Crosswalks should be no less than 6 ft (1.8 m) wide. Crosswalk lines should extend across the full width of pavement. Crosswalks should be marked at all intersections with “substantial conflict” between vehicles and pedestrians.

- **FHWA Markings Guidelines:** Marked crosswalks alone should not be installed at unsignalized pedestrian crossings when speeds are greater than 40 mph.

- ***MUTCD* Signs Standard:** When used at crossings, pedestrian crossing signs shall be supplemented with a diagonal downward-pointing arrow plaque showing the location of the crossing.

- ***MUTCD* Signs Guidance:** When used in advance of a crossing, the W11-2 sign may have a supplemental plaque with the legend AHEAD or XX FEET to provide advance notice to road users of crossing activity.

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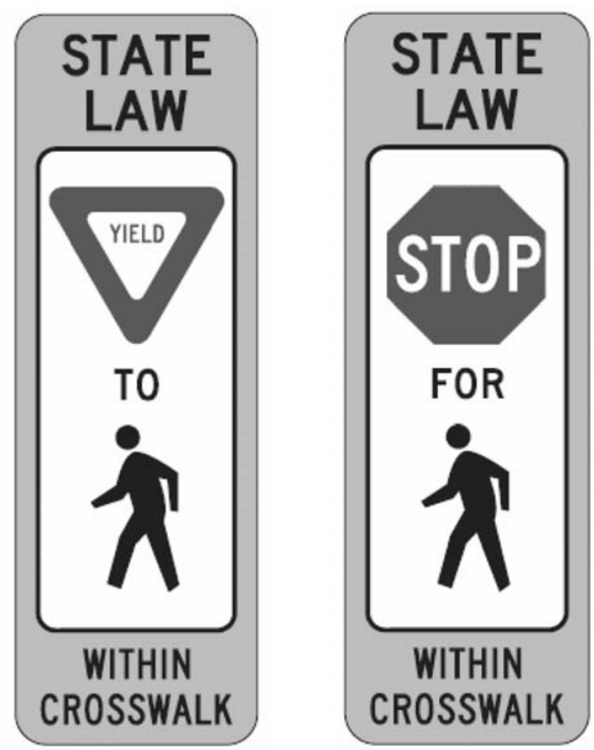
Table A-11. Enhanced Device: In-Street Pedestrian Crossing Signs.

In-Street Pedestrian Crossing Signs

In-Street Pedestrian Crossing signs are regulatory signs placed in the street (on lane edge lines and road centerlines, or in medians). In-Street Pedestrian Crossing signs are described in the 2003 *Manual of Uniform Traffic Control Devices*, in Section 2B.12.

The In-Street Pedestrian Crossing sign (R1-6 or R1-6a) may be used to remind road users of laws regarding right of way at an unsignalized pedestrian crossing. The legend STATE LAW may be shown at the top of the sign if applicable. The legends STOP FOR or YIELD TO may be used in conjunction with the appropriate symbol.



R1-6 **R1-6a**

In-Street Pedestrian Crossing Signs

- ***MUTCD* Standard:** The In-Street Pedestrian Crossing sign shall not be used at signalized locations. The STOP FOR legend shall only be used in states where the state law specifically requires that a driver must stop for a pedestrian in a crosswalk. If used, the In-Street Pedestrian Crossing sign shall have a black legend (except for the red STOP or YIELD sign symbols) and border on either a white and/or fluorescent yellow-green background. If the In-Street Pedestrian Crossing sign is placed in the roadway, the sign support shall comply with the breakaway requirements of the latest edition of AASHTO's specifications.

- ***MUTCD* Guidance:** If an island is available, the In-Street Pedestrian Crossing sign, if used, should be placed on the island.

- ***MUTCD* Option:** The In-Street Pedestrian Crossing sign may be used seasonally to prevent damage in winter because of plowing operations and may be removed at night if the pedestrian activity at night is minimal.

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Table A-12. Enhanced Device: Signs and High-Visibility Markings.

Signs and High-Visibility Markings

Signs and high-visibility markings are warning devices placed at or in advance of the pedestrian crossing. They include fluorescent yellow-green pedestrian crossing signs, other crossing signs, high-visibility crosswalk markings, and other devices that attempt to draw attention to the crossing. They are used in much the same way as conventional signs and markings, but the high-visibility characteristics add prominence to the devices.

Pedestrian Sign (Not in 2003 *MUTCD*), High-Visibility Crosswalk Markings, and Reflectorized Bollards

- **Signs**: Enhanced versions of standard signs may have a fluorescent yellow-green background, or they may have a traditional yellow background made of a material that has higher conspicuity. Other signs may be experimental or may use combinations of standard signs and colors.
- **High-Visibility Markings**: High-visibility markings are similar to their conventional counterparts but have a higher conspicuity and/or reflectorization. Markings should be applied using the same guidance as for conventional markings (should be no less than 6 ft [1.8 m] wide, should extend across the full width of pavement, etc.).

Fluorescent Yellow-Green Sign with Arrow Plaque, Crosswalk Markings, Raised Pavement Markers, and Example of Experimental Use of In-Street Pedestrian Crossing Sign

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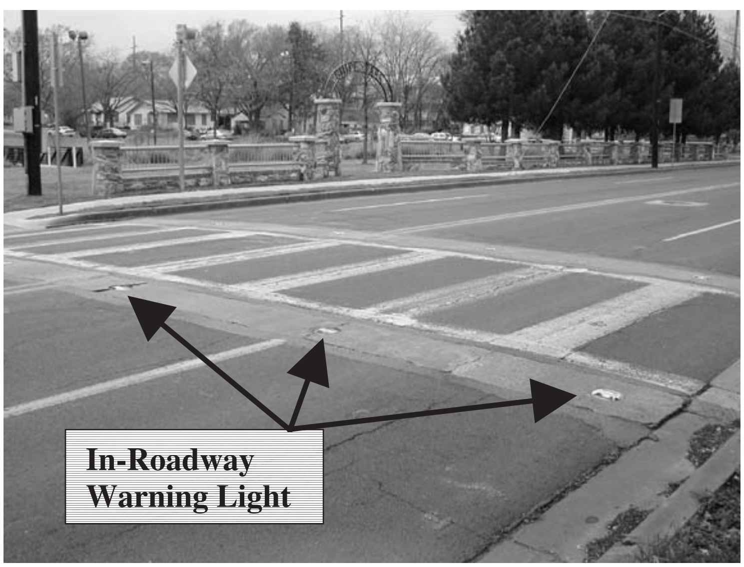
Table A-13. Active Device: In-Roadway Warning Lights.

In-Roadway Warning Lights

In-roadway warning lights at crosswalks provide amber flashing lights that are mounted flush to the pavement surface at the crossing location. The flashing lights can be activated by either a pushbutton or a passive detection technology, such as bollards, video, or microwave sensors.

In Section 4L.01, the 2003 *MUTCD* describes in-roadway warning lights at crosswalks as special types of highway traffic signals installed in the roadway surface to warn road users that they are approaching a condition on or adjacent to the roadway that might not be readily apparent and might require the road users to slow down and/or come to a stop. This includes, but is not necessarily limited to, situations warning of marked school crosswalks, marked midblock crosswalks, marked crosswalks on uncontrolled approaches, marked crosswalks in advance of roundabout intersections, and other roadway situations involving pedestrian crossings.



In-Roadway Warning Lights at Midblock Crosswalk

- ***MUTCD* General Standard:** If used, in-roadway warning lights at crosswalks shall not exceed a height of 0.75 in above the roadway surface.

- ***MUTCD* Standard at Crosswalks:** In-roadway warning lights at crosswalks shall be installed only at marked crosswalks with applicable warning signs, not at crosswalks controlled by Yield signs, Stop signs, or traffic control signals. They shall be installed along both sides of the crosswalk and shall span its entire length. They shall initiate operation on pedestrian actuation and cease at a predetermined time after the pedestrian actuation or, with passive detection, after the pedestrian clears the crosswalk. They shall display a flashing yellow signal indication when actuated, the flash rate of which shall be at least 50, but not more than 60, flashes per minute. There shall be at least one in-roadway light per lane of roadway, with a minimum of two lights for a one-lane one-way roadway and a minimum of three lights for a two-lane roadway. They shall be installed outside the crosswalk, within 3 ft (1 m) of the crosswalk.

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Table A-14. Active Device: Pedestrian Crossing Flags.

Pedestrian Crossing Flags

Pedestrian crossing flags are flags of various colors (typically orange, yellow, or fluorescent yellow-green) mounted on a stick that is held by pedestrians crossing or waiting to cross the street. The flags are typically stored in sign-mounted holders on both sides of the street at crossing locations.

Pedestrian Crossing Flags Stored in Sign-Mounted Holder

- **Pedestrian Usage:** Supplemental plaques may be added at or near the flag holders to explain to pedestrians the proper usage of the flags.
- **Maintenance:** Depending on the location where flags are used, flags will need to be replaced periodically due to normal wear and tear, theft, and/or vandalism. The frequency of replacement depends largely on the pedestrian volumes and weather conditions at the site. A supplemental plaque may be installed near the flag holder as a warning against theft.

Supplemental Usage and Anti-theft Plaques

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Table A-15. Active Device: Overhead Flashing Amber Beacons.

Overhead Flashing Amber Beacons

Overhead flashing amber beacons are mounted on mast arms that extend over the roadway at or in advance of the crossing location. The flashing beacons can be activated by either a pushbutton or a passive detection technology, such as bollards, video, or microwave sensors. Continuously flashing beacons are not included in this category; they would be more appropriately included in the "Enhanced" category of devices.

The alternate flashing is preferred by some agencies over the simultaneous flashing. A strobe pattern is also achievable with light-emitting diode (LED) modules and advance transportation controllers.

Overhead Flashing Amber Beacons with Pedestrian Crossing Sign (Current Version of Sign Does Not Include Crosswalk Markings)

- ***MUTCD* Standard:** A warning beacon shall consist of one or more signal sections of a standard traffic signal face with a flashing circular yellow signal indication in each section. It shall be used only to supplement an appropriate warning or regulatory sign or marker. The beacon shall not be included within the border of the sign except for School Speed Limit sign beacons. The clearance above the pavement for overhead beacons shall be at least 15-ft (4.6-m) but not more than 19-ft (5.8-m).

- ***MUTCD* Guidance:** Warning beacons should be operated only during those hours when the condition or regulation exists. Section 4K.03 of the 2003 *MUTCD* mentions "emphasis for midblock crosswalks" as a specific application of flashing beacons.

Overhead Flashing Amber Beacons with Supplemental Pedestrian Crossing Sign (Older Version of Sign) and Mast-Arm Mounted "PED XING" Sign (Not in 2003 *MUTCD*)

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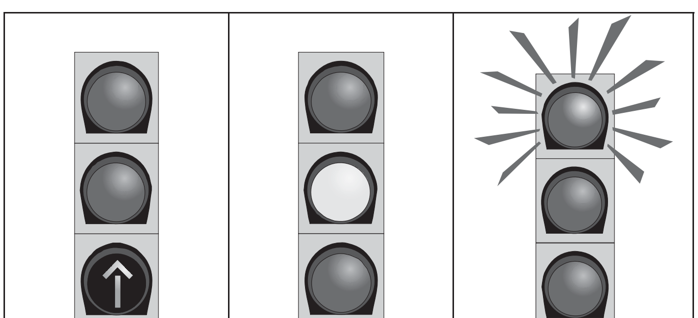
Table A-16. Red Device: Pedestrian Crosswalk Signal.

Pedestrian Crosswalk Signal

A pedestrian crosswalk signal is a special traffic control signal used in Los Angeles to encourage pedestrians to use a crosswalk and to emphasize to vehicles the importance and necessity of yielding to pedestrians in the crosswalk. A pedestrian crosswalk signal has been used in Los Angeles to facilitate pedestrian crossings when other traffic signal warrants were not met. The pedestrian phase for a pedestrian crosswalk signal is activated by a pushbutton. The cycle for vehicles consists of a flashing red indication preceded by a yellow clearance interval, similar to a standard traffic control signal. A pedestrian crosswalk signal dwells in steady green (ball or arrow). It is generally accompanied by a supplemental plaque indicating the signal is intended for pedestrians using the crosswalk and WAIT HERE pavement markings.

- **Los Angeles Pedestrian Crosswalk Signal:** For Los Angeles, a signal at a midblock crossing can be authorized for the purpose of consolidating midblock crossings to a single, preferred point, when the street is at least 50 ft (15 m) wide, the nearest controlled crossing is at least 300 ft (91 m) away, and the marked crosswalk requirements are satisfied (which includes a criteria of 40 or more pedestrians during peak pedestrian hours).

Example of Los Angeles Pedestrian Crosswalk Signal with Supplemental Signing (Not in 2003 *MUTCD*) on Mast Arm (Note Green Arrow)



Dwells in Green Arrow	Upon Activation, Steady Yellow for 3 to 6 s	Flashing Red during Pedestrian Interval

Example of Phasing for Pedestrian Crosswalk Signal

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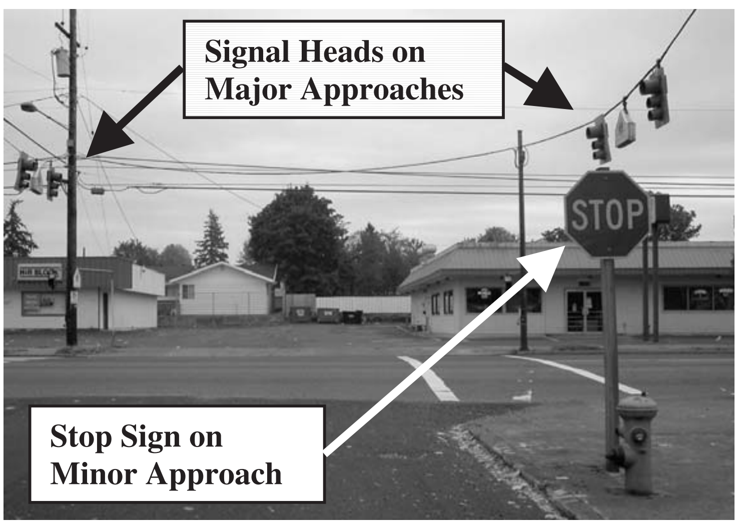
Table A-17. Red Device: Half Signals.

Half Signals

A half signal (also known as an intersection pedestrian signal) is a standard traffic signal with red, yellow, and green indications that is located at an intersecting cross street with Stop control. The pedestrian phase for a half signal is typically activated by a pushbutton. In the United States, most half signals dwell in steady green, whereas most half signals in British Columbia dwell in flashing green.

Half signals are experimental and are not currently included in the *MUTCD*. Permission for experimentation is needed.



Intersection Pedestrian Signal (Half Signal)

- **Guidance:** Half signals are used to provide signal control for a pedestrian crossing the major street while minimizing delay for major street traffic by retaining Stop sign control on the minor street. This treatment has been used at locations where there is heavy pedestrian demand to cross the major street but the side street traffic on the minor approach is light. The lack of signal control on the side street does not attract more traffic to the street as conventional intersection signals would.

- **Installation and Operation:** The cost of installation is significant. Drivers on side streets may be confused about right-of-way assignment: the side street right-of-way relies on gaps in main street traffic to enter or cross the main street. If the crosswalk is clear, drivers on side streets may use the gap created by the signal to proceed through the intersection. This treatment has been tested in several cities including Portland, Oregon; Seattle, Washington; and Fairfax, Virginia.

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Table A-18. Red Device: HAWK Beacon Signals.

<table>
<tr><td colspan="2">HAWK</td></tr>
<tr><td>A HAWK beacon signal provides yellow and red indications. The current configuration for a HAWK is two red lenses above a yellow lens in a “Mickey Mouse Ears” format. The HAWK beacon signal, used exclusively in Tucson and Pima County, Arizona, dwells in a dark mode until activated by a pedestrian by means of a pushbutton.

The HAWK is currently not included in the MUTCD. Permission for experimentation is needed.</td>
<td rowspan="2">Description: The objective of a HAWK (high-intensity activated crosswalk) signal is to stop vehicles to allow pedestrians to cross while also allowing vehicles to proceed as soon as the pedestrians have passed. It is a combination of a beacon flasher and a traffic control signal. This application provides a pedestrian crossing without signal control for the side street.
Operation: The inclusion of the alternating flashing red permits stop-and-go vehicle operations after a pedestrian has cleared the crosswalk.
Observations: Drivers are more likely to stop for a device that displays a red indication. Driver education has been an active component in those communities using a HAWK signal. Confusion may result from the dark beacon signal display, as drivers may interpret it as a power outage; however, that has not been a problem where implemented.</td></tr>
<tr><td>

HAWK Signal


Close-Up of HAWK Signal Head</td></tr>
</table>

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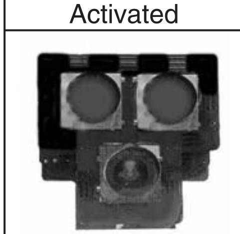
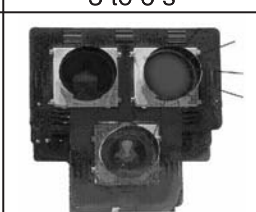
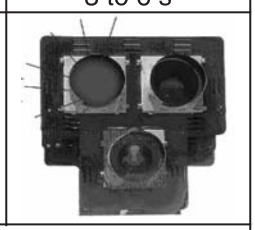
Table A-19. Red Device: Pedestrian Beacon.

Proposed Pedestrian Beacon

A pedestrian beacon is a proposed special highway traffic control signal used at some locations for pedestrians waiting to cross or crossing the street. A pedestrian beacon is proposed to be considered for installation at a midblock location that does not meet other traffic signal warrants to facilitate pedestrian crossings. The pedestrian phase for a pedestrian beacon would be activated by a pedestrian. The red portion of the cycle for vehicles consists of a sequence of a steady red indication (during the pedestrian crossing interval) followed by flashing red indications (during the pedestrian clearance interval).

This device has been suggested to be included in future editions of the *MUTCD*.

		
Dark until Activated	Flashing Yellow for 3 to 6 s	Steady Yellow for 3 to 6 s
		
Steady Red during Pedestrian Interval	Alternating Flashing Red during Pedestrian Clearance Interval	

Example of Phase Sequence for a Pedestrian Beacon

- **Proposed Guidance for the *MUTCD*:** If a traffic control signal is not justified under the signal warrants of Chapter 4C and if gaps in traffic are not adequate to permit reasonably safe pedestrian crossings, or if the speed for vehicles approaching on the major street is too high to permit reasonably safe street crossings for pedestrians, or if pedestrian delay is excessive, installing a pedestrian traffic control signal should be considered.

- **Proposed Sign to Accompany a Pedestrian Beacon:**

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Table A-20. Signal: Traffic Control Signals.

Traffic Control Signals

Standard traffic signals and warrants for their consideration are described in the *MUTCD*. In particular, Warrant 4 of the 2003 edition deals with traffic signals for pedestrians.

The pedestrian volume signal warrant is intended for application where the traffic volume on a major street is so heavy that pedestrians experience excessive delay in crossing the major street. A signal may not be needed at the study location if adjacent coordinated traffic control signals consistently provide gaps of adequate length for pedestrians to cross the street.

Traffic Control Signal with Pedestrian Crossing Sign (Current Version of Sign Does Not Include Crosswalk Markings)

Pedestrian Using Pushbutton Detector to Activate WALK Indication at Traffic Control Signal

- ***MUTCD* Standard:** The need for a traffic control signal at an intersection or a midblock crossing shall be considered if an engineering study finds that the appropriate criteria are met. This warrant shall not be applied at locations where the distance to the nearest traffic signal is less than 300 ft (91 m) unless the proposed signal will not restrict the progressive movement of traffic.

- ***MUTCD* Guidance:** If at an intersection, the signal should be traffic actuated and include pedestrian detectors. If installed within a signal system, the signal should be coordinated. If at a midblock crossing, the signal should be pedestrian actuated, parking and other obstructions should be prohibited for at least 100 ft (31 m) in advance of and at least 20 ft (6.1 m) beyond the crosswalk, and the installation should include standard signs and pavement markings.

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- Lalani, N., and ITE Pedestrian and Bicycle Task Force. *Alternative Treatments for At-Grade Pedestrian Crossings*. ITE Informational Report, ITE, Washington, D.C., 2001.
- Zegeer, C., J. Stuart, and H. Huang. *Safety Effects of Marked vs. Unmarked Crosswalks at Uncontrolled Crossing Locations*. FHWA, Washington, D.C., 2001.
- PedSafe: Pedestrian Safety Guide and Countermeasure Selection System. http://www.walkinginfo.org/pedsafe/

Illustrations of Guidelines

Graphs were generated to illustrate the guidelines for the readers and are included as Figures A-6 through A-19. These graphs should be used only when the major-road speed, the pedestrian walking speed, and the crossing distance are matched to the value presented at the top of the graph. For other situations, the reader should use the equations listed in the worksheets.

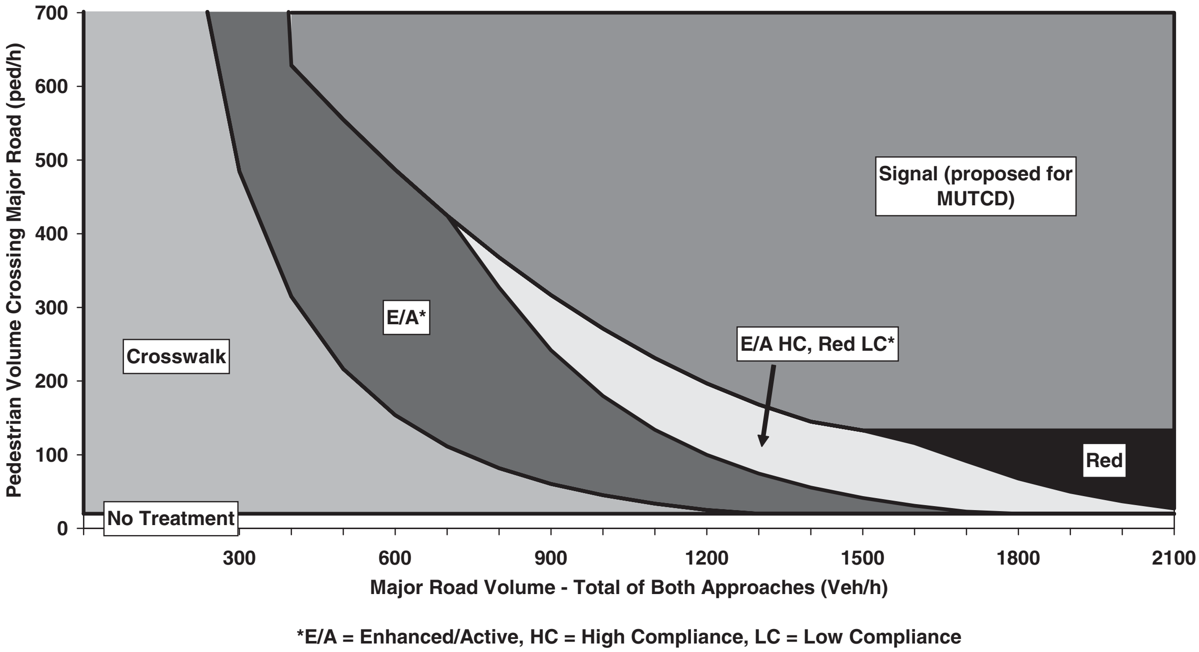

Figure A-6. Guidelines Plot, 34 ft (10.4 m) Pavement, ≤35 mph (55 km/h), 3.5 ft/s (1.1 m/s) Walking Speed.

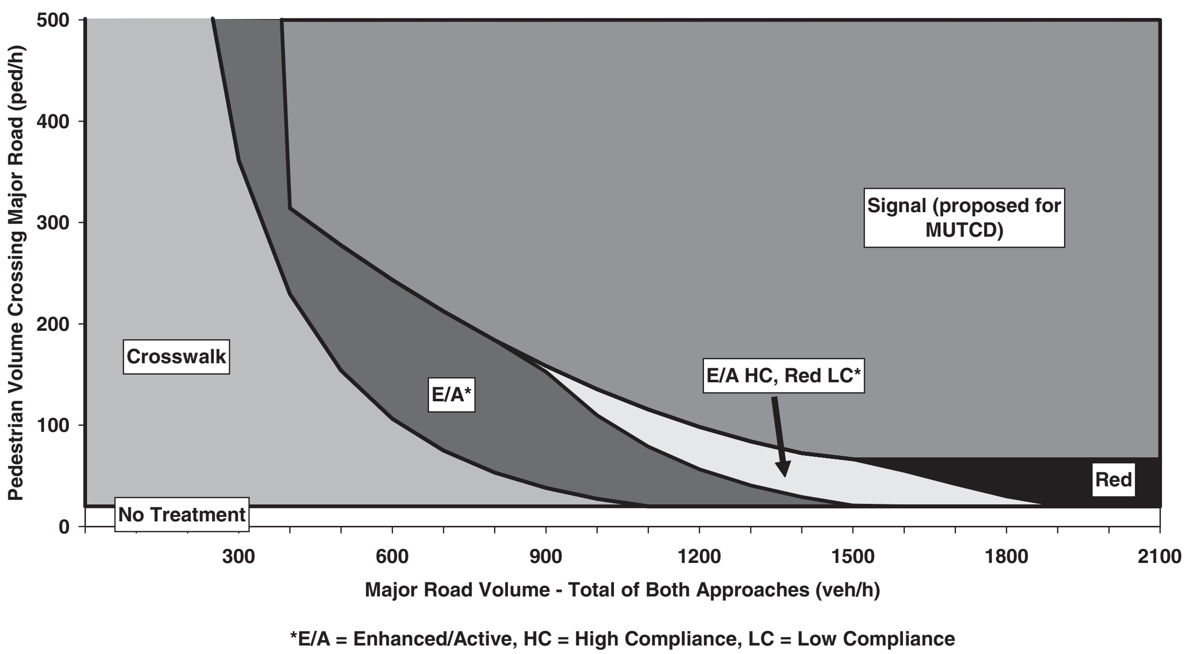

Figure A-7. Guidelines Plot, 34 ft (10.4 m) Pavement, ≤35 mph (55 km/h), 3.0 ft/s (0.9 km/h) Walking Speed.

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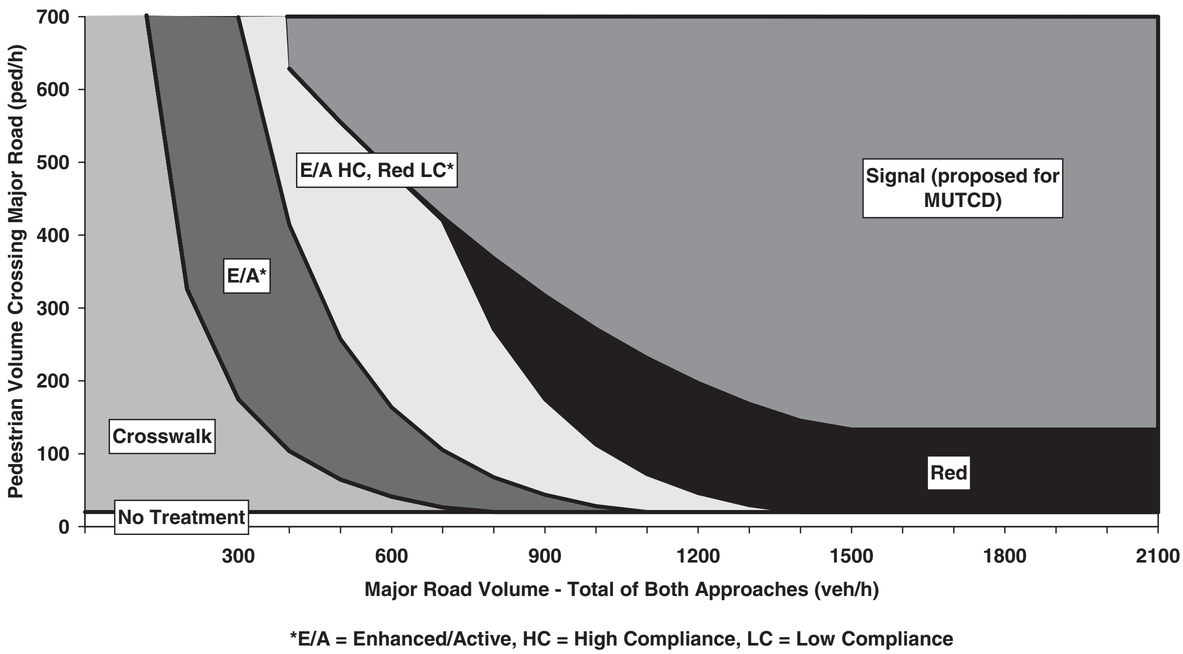

Figure A-8. Guidelines Plot, 56 ft (17 m) Pavement, ≤35 mph (55 km/h), 3.5 ft/s (1.1 m/s) Walking Speed.

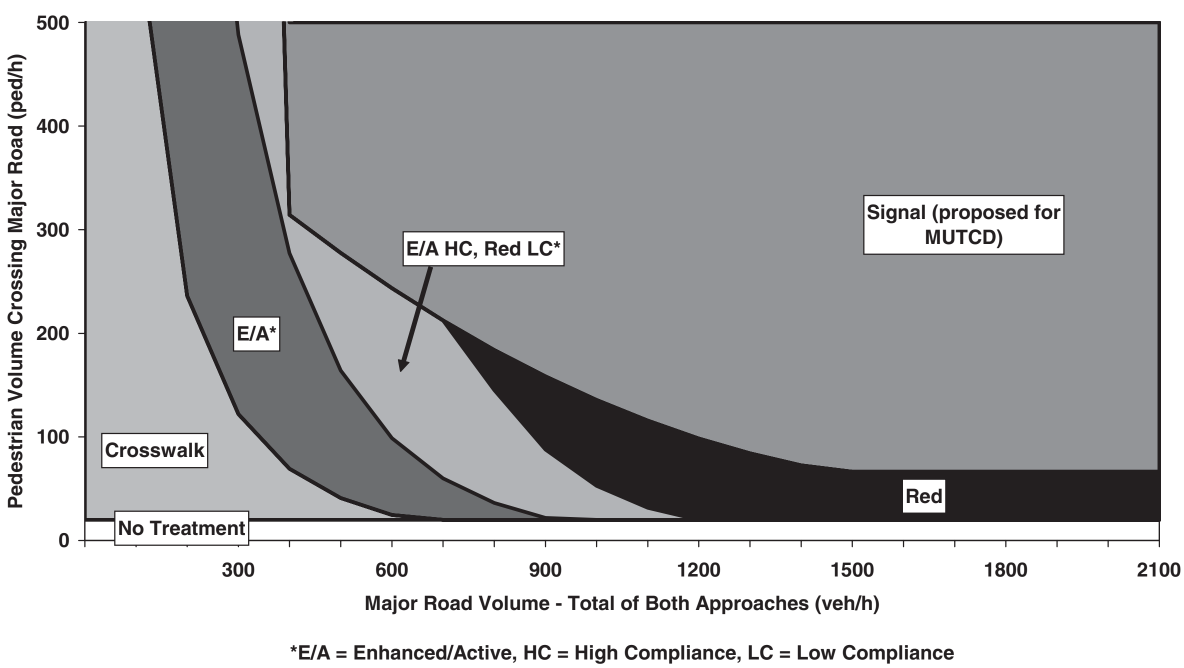

Figure A-9. Guidelines Plot, 56 ft (17 m) Pavement, ≤35 mph (55 km/h), 3.0 ft/s (0.9 m/s) Walking Speed.

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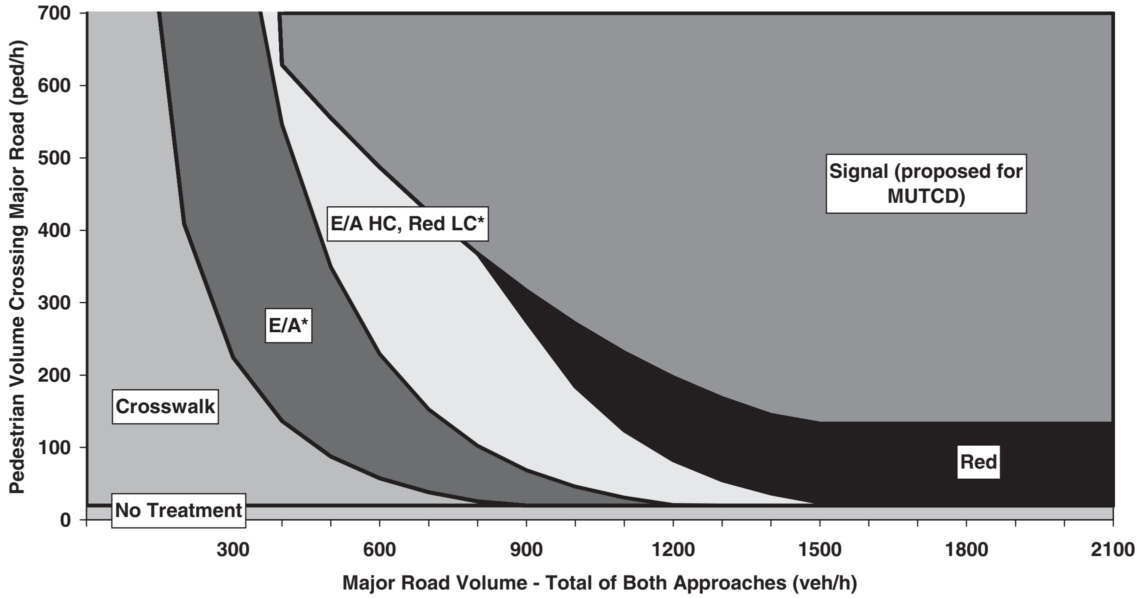
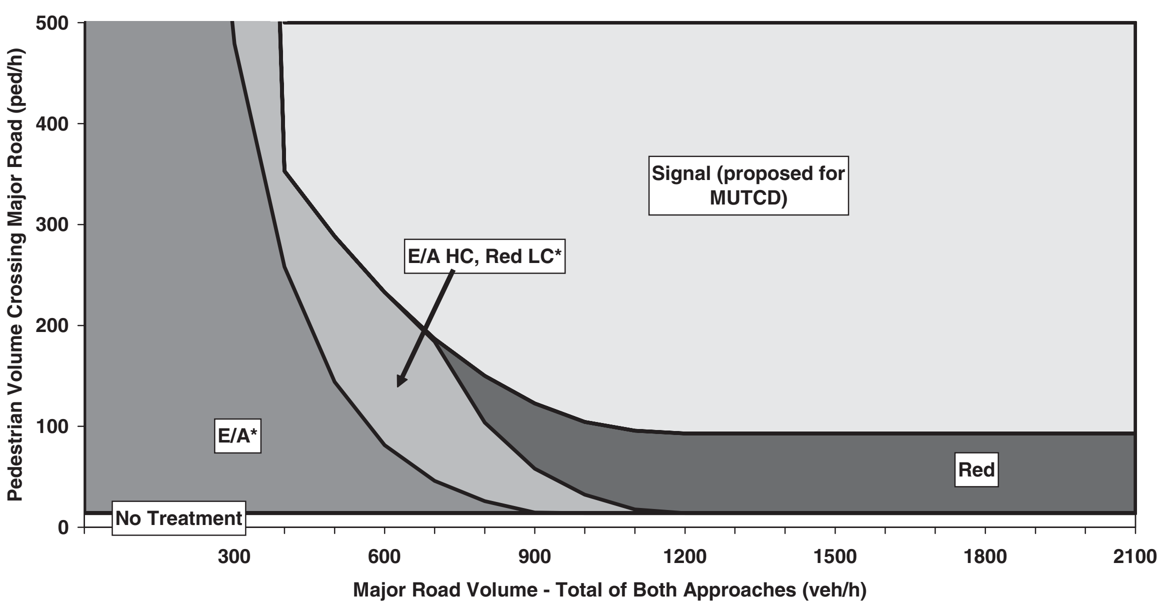


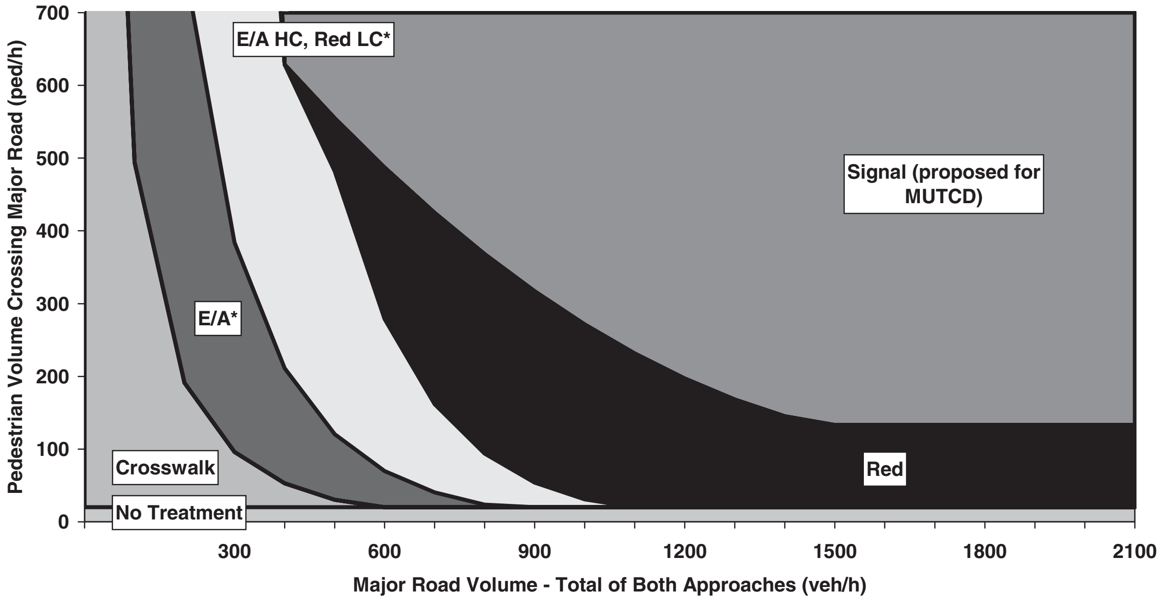
*E/A = Enhanced/Active, HC = High Compliance, LC = Low Compliance

Figure A-10. Guidelines Plot, 50 ft (17 m) Pavement, ≤35 mph (55 km/h), 3.5 ft/s (1.1 m/s) Walking Speed.



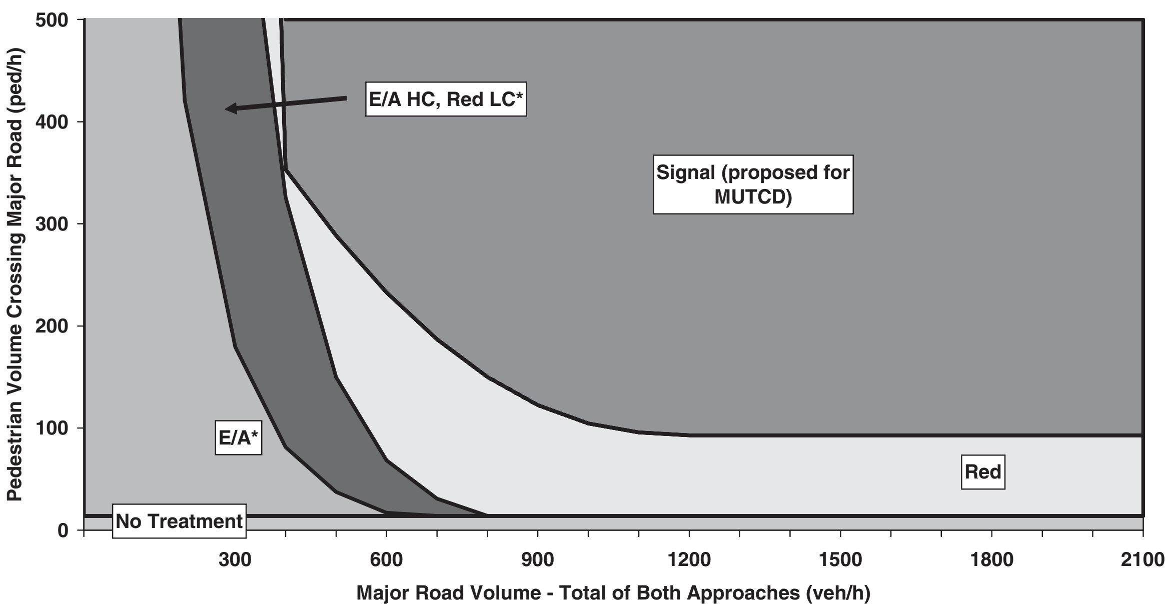
*E/A = Enhanced/Active, HC = High Compliance, LC = Low Compliance

Figure A-11. Guidelines Plot, 50 ft (17 m) Pavement, >35 mph (55 km/h), 3.5 ft/s (1.1 m/s) Walking Speed.



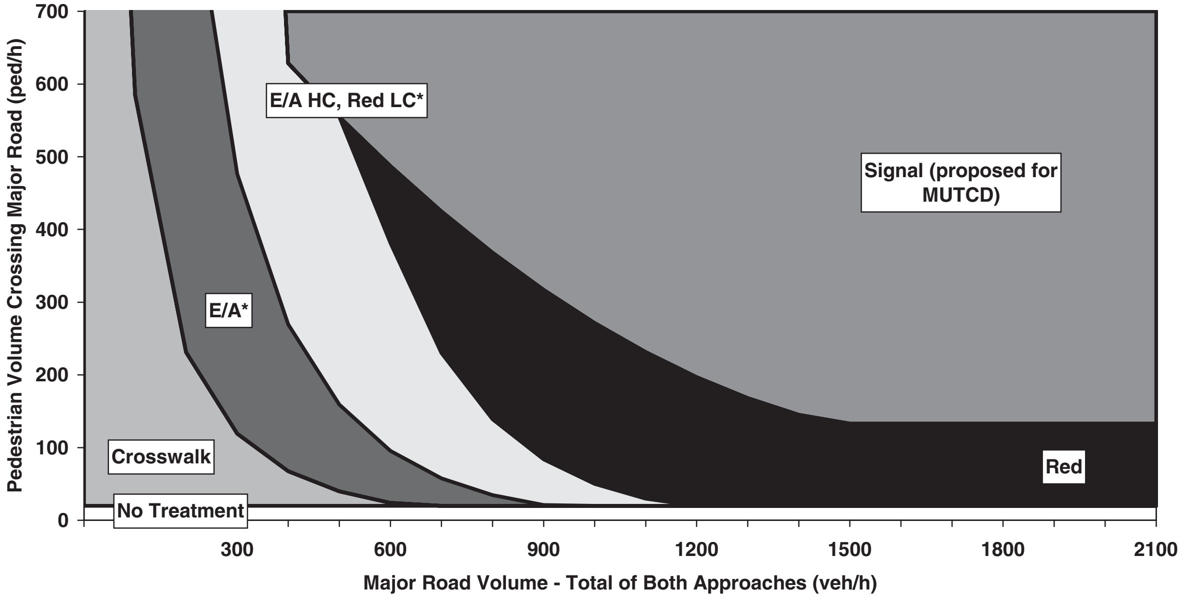
*E/A = Enhanced/Active, HC = High Compliance, LC = Low Compliance

Figure A-12. Guidelines Plot, 72 ft (22 m) Pavement, ≤35 mph (55 km/h), 3.5 ft/s (1.1 m/s) Walking Speed.



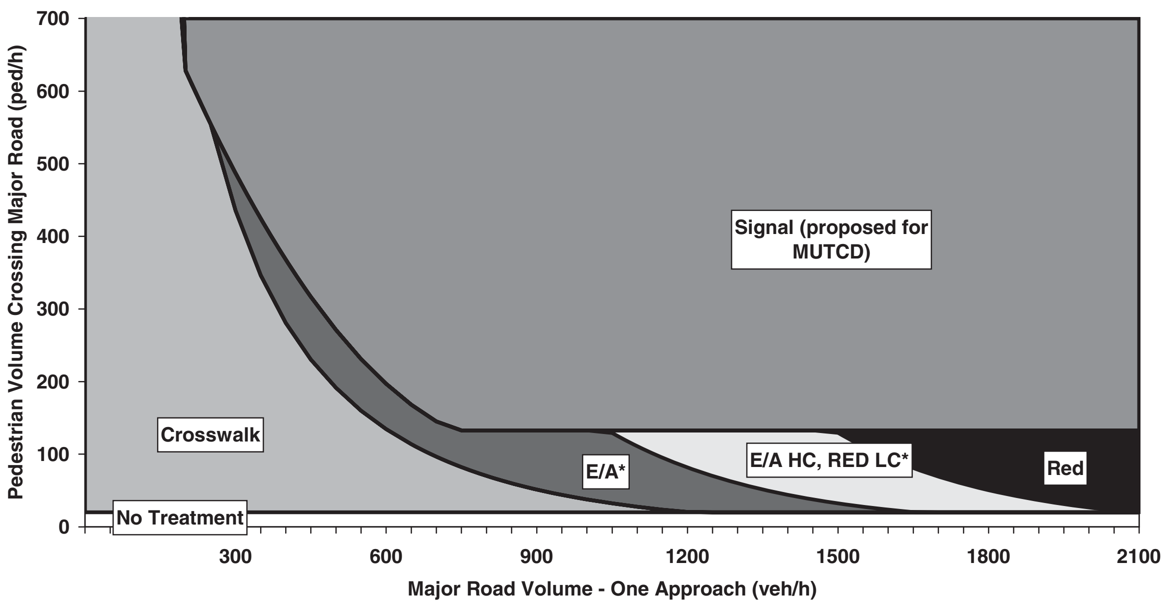
*E/A = Enhanced/Active, HC = High Compliance, LC = Low Compliance

Figure A-13. Guidelines Plot, 72 ft (22 m) Pavement, >35 mph (55 km/h), 3.5 ft/s (1.1 m/s) Walking Speed.



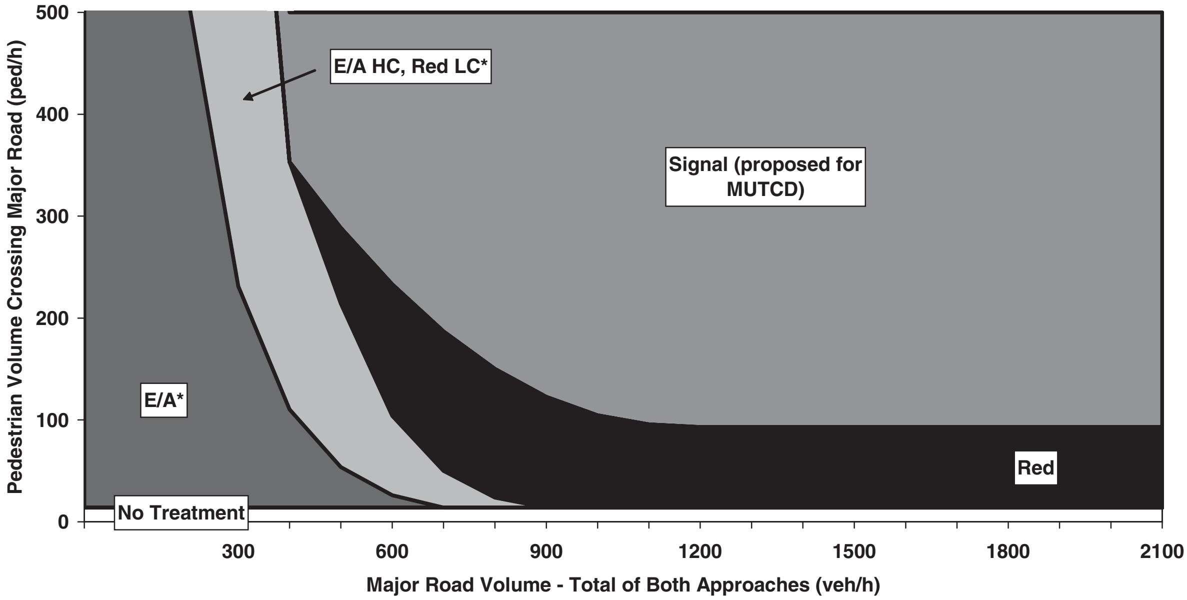
*E/A = Enhanced/Active, HC = High Compliance, LC = Low Compliance

Figure A-14. Guidelines Plot, 66 ft (20 m) Pavement, ≤35 mph (55 km/h), 3.5 ft/s (1.1 m/s) Walking Speed.



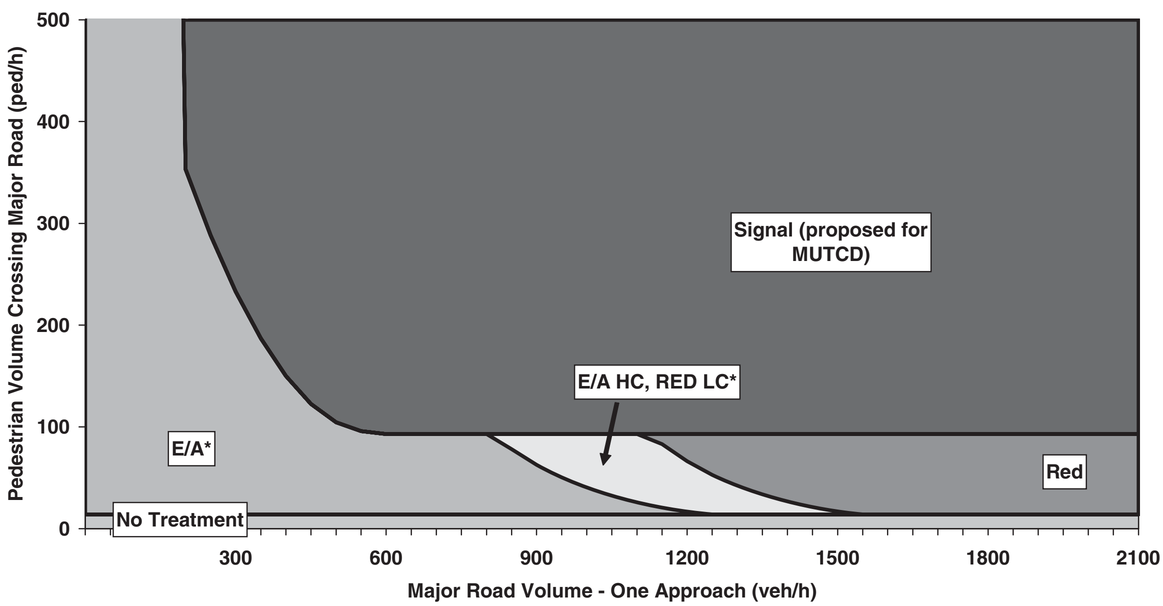
*E/A = Enhanced/Active, HC = High Compliance, LC = Low Compliance

Figure A-15. Guidelines Plot, Divided Roadway with Pedestrian Refuge Island, Crossing 36 ft (11 m) Pavement, ≤35 mph (55 km/h), 3.5 ft/s (1.1 m/s) Walking Speed (Plot Assumed 50/50 Volume Split for Signal Curve).



*E/A = Enhanced/Active, HC = High Compliance, LC = Low Compliance

Figure A-16. Guidelines Plot, 66 ft (20 m) Pavement, >35 mph (55 km/h), 3.5 ft/s (1.1 m/s) Walking Speed.



*E/A = Enhanced/Active, HC = High Compliance, LC = Low Compliance

Figure A-17. Guidelines Plot, Divided Roadway with Pedestrian Refuge Island, Crossing 36 ft (11 m) Pavement, >35 mph (55 km/h), 3.5 ft/s (1.1 m/s) Walking Speed (Plot Assumed 50/50 Volume Split for Signal Curve).

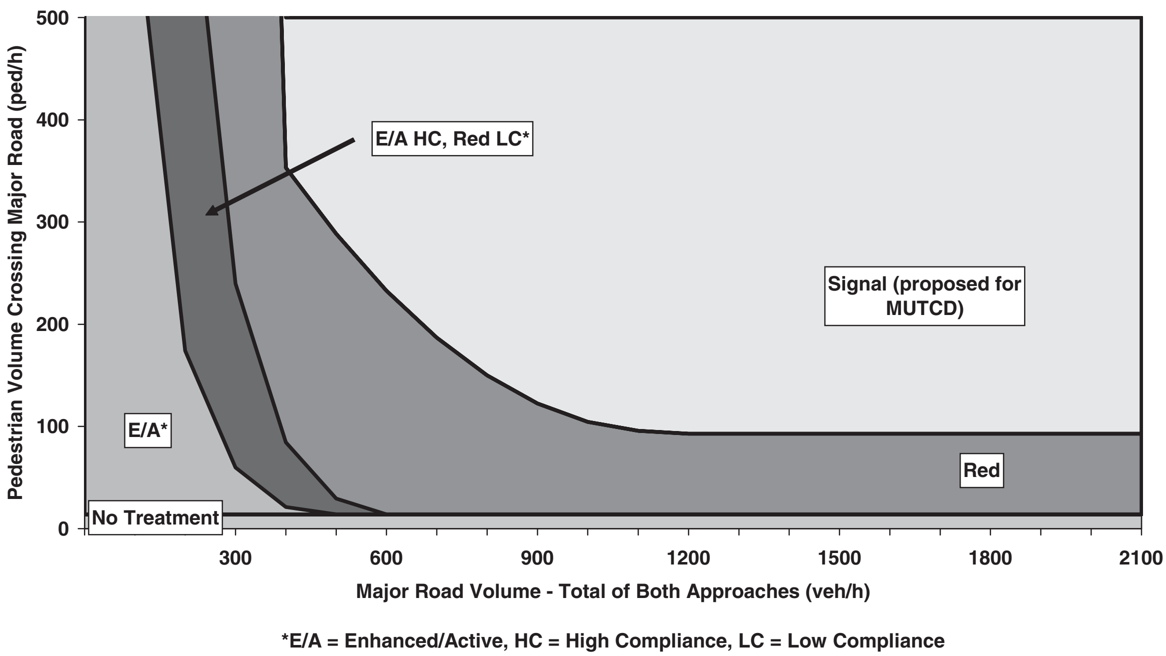


Figure A-18. Guidelines Plot, 100 ft (31 m) Pavement, >35 mph (55 km/h), 3.5 ft/s (1.1 m/s) Walking Speed.

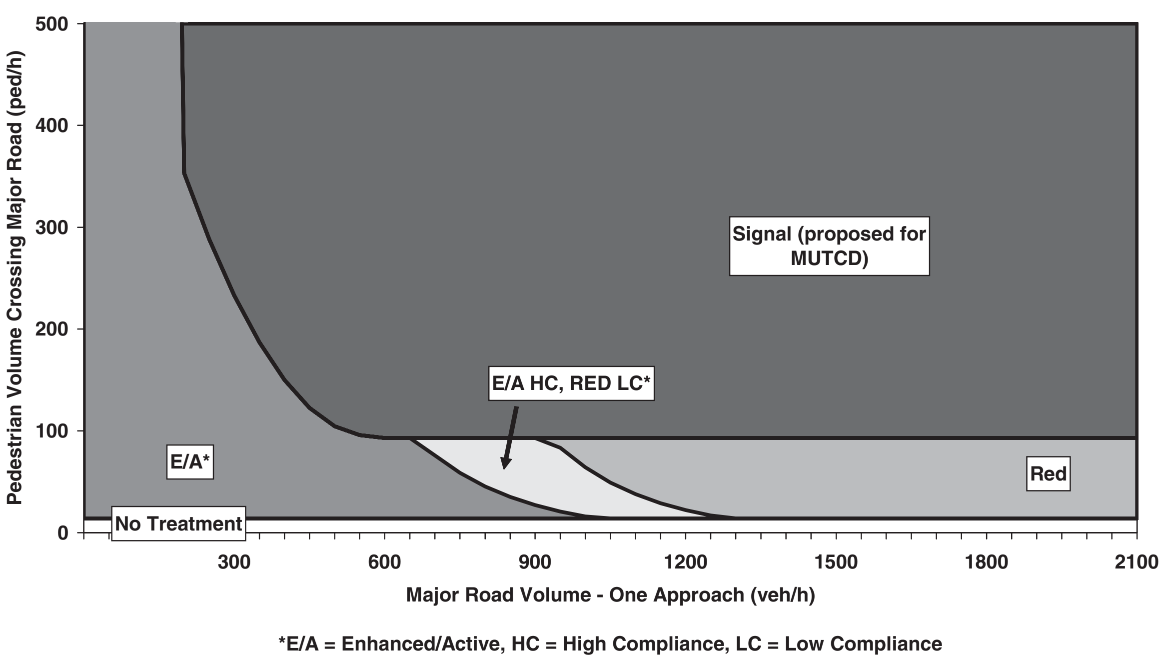


Figure A-19. Guidelines Plot, Divided Roadway with Pedestrian Refuge Island, Crossing 44 ft (13.4 m) Pavement, >35 mph (55 km/h), 3.5 ft/s (1.1 m/s) Walking Speed (Plot Assumed 50/50 Volume Split for Signal Curve).

APPENDIXES B THROUGH O

Appendixes B through O are available as *TCRP Web-Only Document 30/NCHRP Web-Only Document 91* at the TRB website.

The appendixes are as follows:

- Appendix B – Proposed Changes to MUTCD
- Appendix C – Literature Review of Pedestrian Crossing Treatments at Uncontrolled Locations
- Appendix D – Pedestrian Crossing Treatments
- Appendix E – Summary of Pedestrian Crossing Treatment Evaluations
- Appendix F – Pedestrian Crossing Installation Guidelines
- Appendix G – International Signal Warranting Practices
- Appendix H – Adequacy of Pedestrian Signal Warrant
- Appendix I – Suggested Issues to Consider When Revising the Pedestrian Signal Warrant
- Appendix J – Survey of Providers
- Appendix K – On-Street Pedestrian Surveys
- Appendix L – Motorist Compliance to Engineering Treatments at Marked Crosswalks
- Appendix M – Walking Speed
- Appendix N – Gap Acceptance
- Appendix O – Guidelines Development

Abbreviations and acronyms used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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