TCRP Web-Only Document 30 (Project D-8)/
NCHRP Web-Only Document 91 (Project 3-71): Contractor's Final Report – Appendices B to O

Improving Pedestrian Safety at Unsignalized Crossings

Appendices B to O

Prepared for:

Transit Cooperative Research Program
National Cooperative Highway Research Program

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

Submitted by:

Kay Fitzpatrick, Shawn Turner, Marcus Brewer, Paul Carlson,
Brooke Ullman, Nada Trout, Eun Sug Park, Jeff Whitacre,
Texas Transportation Institute, College Station, Texas

and

Nazir Lalani, Traffex Engineers, Inc., Ventura, California

and

Dominique Lord, Texas A&M University, College Station, Texas

March 2006

ACKNOWLEDGMENT

This work was sponsored by the Federal Transit Administration (FTA) in cooperation with the Transit Development Corporation (TDC) and the American Association of State Highway and Transportation Officials (AASHTO) in cooperation with the Federal Highway Administration (FHWA). It was conducted through the Transit Cooperative Research Program (TCRP) and the National Cooperative Highway Research Program (NCHRP), which are administered by the Transportation Research Board (TRB) of the National Academies.

COPYRIGHT PERMISSION

DISCLAIMER

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. William A. Wulf is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, on its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both the Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. William A. Wulf are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is a division of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's mission is to promote innovation and progress in transportation through research. In an objective and interdisciplinary setting, the Board facilitates the sharing of information on transportation practice and policy by researchers and practitioners; stimulates research and offers research management services that promote technical excellence; provides expert advice on transportation policy and programs; and disseminates research results broadly and encourages their implementation. The Board's varied activities annually engage more than 5,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.
www.TRB.org

www.national-academies.org

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENTS

The research reported herein was performed under Transit Cooperative Research Program/National Cooperative Highway Research Program (TCRP/NCHRP) Project D-08/3-71 by the Texas Transportation Institute (TTI). Texas A&M Research Foundation was the contractor for this study.

Kay Fitzpatrick of the Texas Transportation Institute 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 the Texas Transportation Institute. 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, TAMU), and Jeff Whitacre (Graduate Research Assistant, TTI). The work was performed under the general supervision of Dr. Fitzpatrick.

The authors would also like to recognize the following individuals with TTI for assistance with the research:

- Collecting field data: Todd Hausman (Associate Research Specialist), Laura Sandt (Research Associate), Andrew Holick (Assistant Transportation Researcher), and Gary Barricklow (Traffic Surveyor)
- Reducing field data: Todd Hausman, Megan Kubecka, Charles Stevens, Tim Wolff, Pammy Katsabas, Melissa Ghrist, Brianne McEwen, Amber Holguin, Stephanie Sandt, Kathleen Newton, and Steven Wilcox
- Report preparation: Denise Robledo and Maria Medrano

The authors wish to acknowledge the many individuals who contributed to this research by participating in the focus groups, on-street surveys, and on-site interviews, along with those who assisted in identifying potential study sites for the Phase II field studies. Those that hosted members of the research team during the on-site interviews included: Dan Bergenthal (Salt Lake City, Utah); Richard Nassi, Shellie Ginn, George Caria (Tucson, Arizona); Michael Cynecki, Thomas Godbee, Ron Robinson, Chuck Italiano (Phoenix, Arizona); Lucy Dyke, Beth Rolandson (Santa Monica, California); Wayne Tanda, John Fisher (Los Angeles, California); Julie Mercer-Matlick, Paula Reeves, Randy Wesselman (Olympia, Washington); Pat O'Neill (University Place, Washington); Robert Spillar, Brian Kemper, Megan Hoyt, Ross Hudson (Seattle, Washington); David Godfrey (Kirkland, Washington); Mark Poch, Kurt Latt (Bellevue, Washington); Jeff Palmer, Susan Byszeski (Redmond, Washington); and Bill Kloos, Jamie Jeffreys, Jean Senechal, Basil Christopher (Portland, Oregon).

Several individuals also assisted the research team with identifying study sites and coordinating the field data collection including: Richard Nassi (Tucson Department of Transportation [DOT]); John Fisher (Los Angeles DOT); Dan Bergenthal (Salt Lake City Corporation); Bill Kloos, Jean Senechal (Portland Office of Transportation); Lucy Dyke, Beth Rolandson (City of Santa Monica Planning and Community Development); Jeff Palmer, Susan Byszeski (City of Redmond); David Godfrey (City of Kirkland Public Works); Brian Kemper,

Megan Hoyt (Seattle Transportation); Eric Tabacek, Ed Paulis (Maryland State Highway Administration); David Gerard (City of Austin); and Ken Fogle (City of College Station).

Individuals who participated in the workshop on evaluating the pedestrian signal warrant at selected locations include: Ruth Smith, Bill Kloos, Mohamed Yussef, Sandra Marks, Raja Sethuraman, Monica Suter, Anne Hernandez, Nancy Cooper, Colleen Hill, Rock Miller, Crystal Killian, Jeffrey Bagdade, and Bob Mabry.

Individuals who donated their time to review the draft *Guidelines for Pedestrian Crossing Treatments* include: Richard Nassi (City of Tucson), David Gerard (City of Austin), Monica Suter (City of Santa Ana), Mark Meisinger (City of Portland), Tom Hicks (Maryland State Highway Administration), and John Fisher (City of Los Angeles).

ABSTRACT

A recent research project jointly sponsored by the Transit Cooperative Research Program and the National Cooperative Highway Research Program had two main objectives: (a) 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 (b) 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, traffic volume, etc.) 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 the findings from the field studies on walking speed and motorist compliance. Pedestrian walking speed recommendations were 3.5 ft/s (1.07 m/s) for general population and 3.0 ft/s (0.9 m/s) for older or less able population. Motorist compliance (yielding or stopping where required) was the primary measure of effectiveness for engineering treatments at unsignalized roadway crossings. The study found that the crossing treatment does have an impact on motorist compliance, and other factors influencing the treatment effectiveness were number of lanes being crossed and posted speed limit.

APPENDIX B

PROPOSED CHANGES TO MUTCD

PROPOSED CHANGE I – PEDESTRIAN SIGNAL WARRANT

Following is a reproduction of the Manual of Uniform Traffic Control Devices (*MUTCD*) (*1*) sections with strike-outs and underlines showing the recommended changes to the Manual.

Section 4C.05 Warrant 4, Pedestrian Volume

Support:

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.

Standard:

The need for a traffic control signal at an intersection or midblock crossing shall be considered if an engineering study finds ~~that the both of the following criteria are met:~~ <u>that one of the following criteria is met:</u>

~~A. The pedestrian volume crossing the major street at an intersection or midblock location during an average day is 100 or more for each of any 4 hours or 190 or more during 1 hour; and~~
~~B. There are fewer than 60 gaps per hour in the traffic stream of adequate length to allow pedestrians to cross during the same period when the pedestrian volume criterion is satisfied. Where there is a divided street having a median of sufficient width for pedestrians to wait, the requirement applies separately to each direction of vehicular traffic.~~

A. <u>For each of any 4 hours of an average day, the plotted points representing the vehicles per hour on the major street (total of both approaches) and the corresponding pedestrians per hour crossing major roadway (total of all crossings) all fall above the curve in Figure 4C-4.</u>

B. <u>For 1 hour (any four consecutive 15-minute periods) of an average day the plotted point representing the vehicles per hour on the major street (total of both approaches) and the corresponding pedestrians per hour crossing major roadway (total of all crossings) falls above the curve in Figure 4C-6.</u>

The Pedestrian Volume signal warrant shall not be applied at locations where the distance to the nearest traffic control signal <u>or all-way Stop</u> is less than 300 ft (90 m), unless the proposed traffic control signal will not restrict the progressive movement of traffic.

If this warrant is met and a traffic control signal is justified by an engineering study, the traffic control signal shall be equipped with pedestrian signal heads conforming to requirements set forth in Chapter 4E.

Option:

If the posted or statutory speed limit or the 85th-percentile speed on the major street exceeds 35 mph (55 km/h), or if the intersection lies within the built-up area of an isolated community having a population of less than 10,000, or where a major transit stop is present, Figure 4C-5 may be used in place of Figure 4C-4 to satisfy criteria A or Figure 4C-7 may be used in place of Figure 4C-6 to satisfy criteria B.

Guidance:

If this warrant is met and a traffic control signal is justified by an engineering study, then:

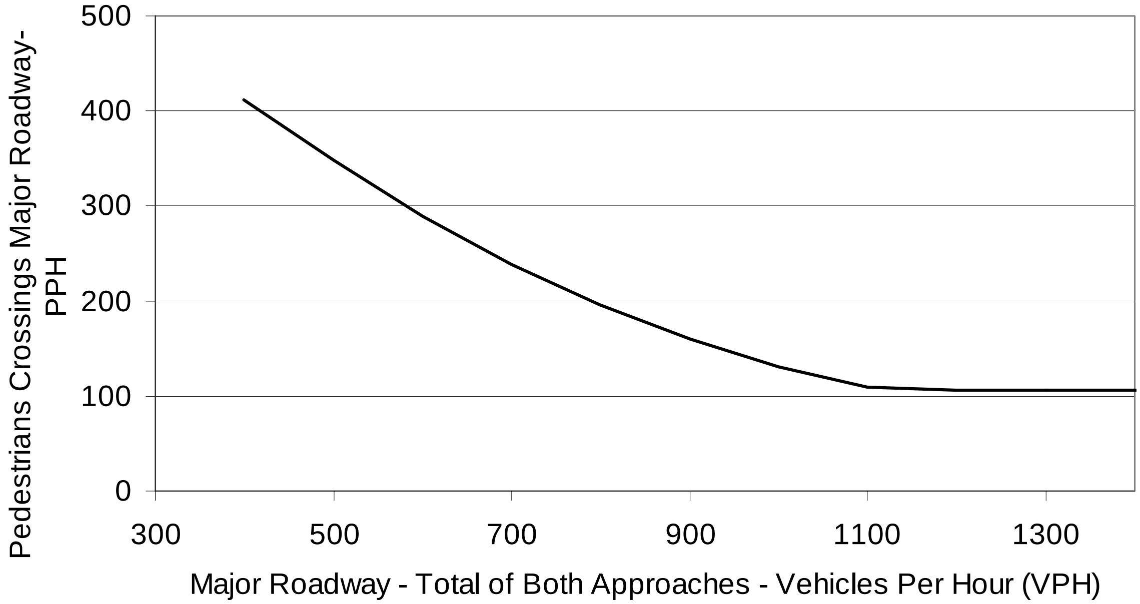
A. If at an intersection, the traffic control signal should be traffic-actuated and should include pedestrian activation ~~detectors~~.
B. If at a nonintersection crossing, the traffic control signal should be pedestrian-actuated, parking and other sight obstructions should be prohibited for at least 100 ft (30 m) in advance of and at least 20 ft (6.1 m) beyond the crosswalk, and the installation should include suitable standard signs and pavement markings.
C. Furthermore, if installed within a signal system, the traffic control signal should be coordinated.

Option:

The criterion for the pedestrian volume crossing the major roadway may be reduced as much as 50 percent if the ~~average~~ 15th percentile crossing speed of pedestrians is less than 3.5 ft/sec (1.1 m/sec) ~~1.2 m/sec (4 ft/sec).~~

A traffic control 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.~~, even if the rate of gap occurrence is less than one per minute.~~

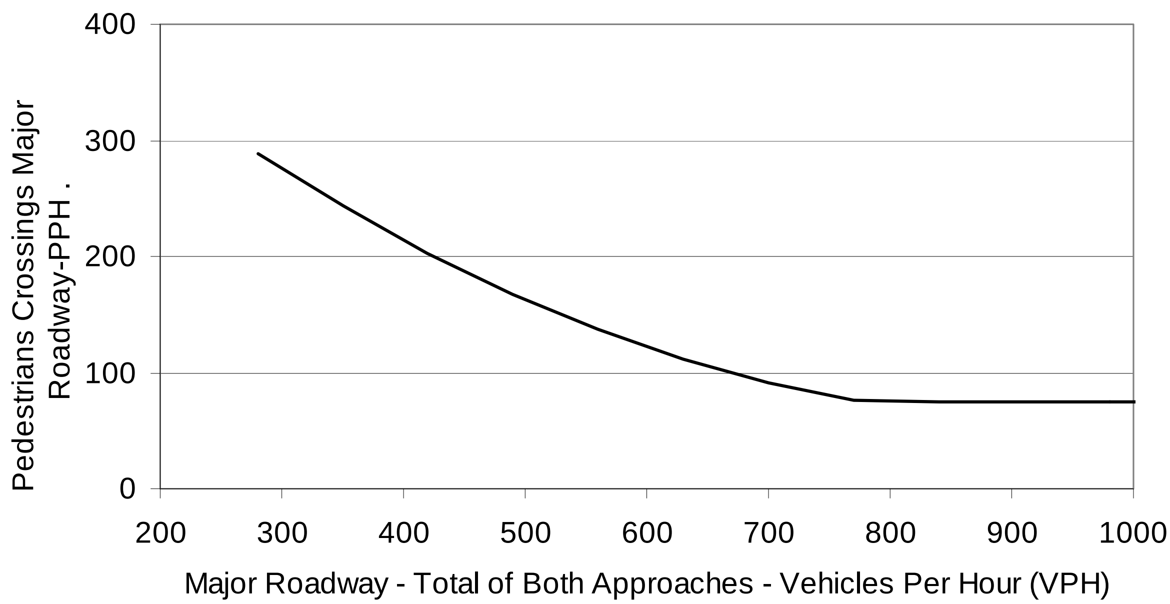
Figure B-1. Proposed MUTCD Figure 4C-4. Warrant 4, Four-Hour Volume



*Note: 107 pph applies as the lower threshold volume.

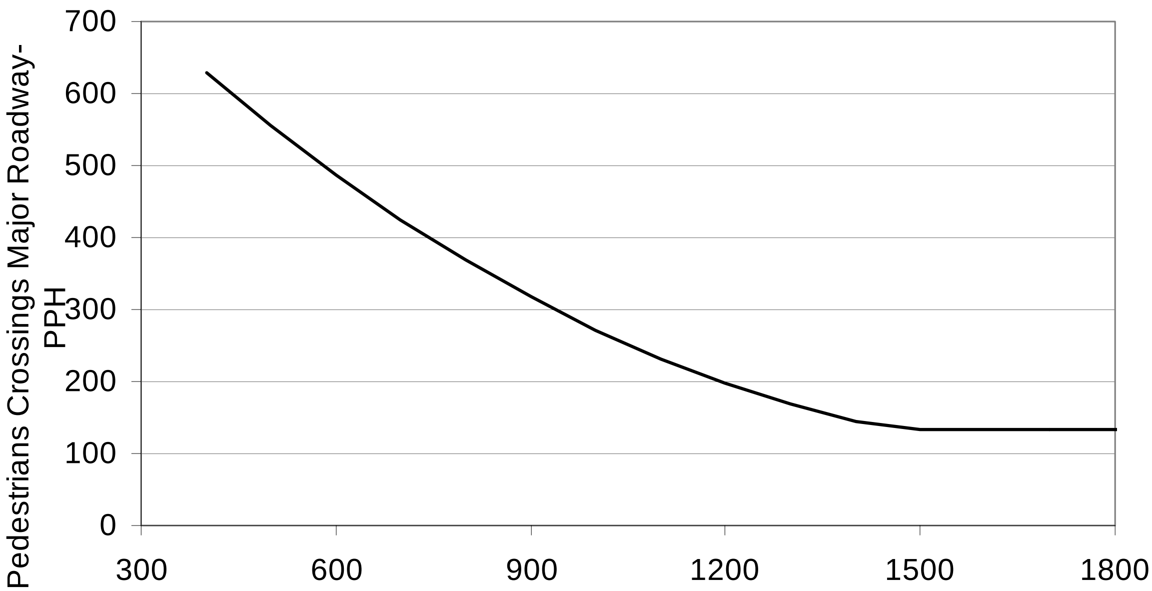
Figure B-2. Proposed MUTCD Figure 4C-5. Warrant 4, Four-Hour Volume (70% Factor)

Community less than 10,000 population or above 55 km/h or above 35 mph on major street or where a major transit stop is present



*Note: 75 pph applies as the lower threshold volume.

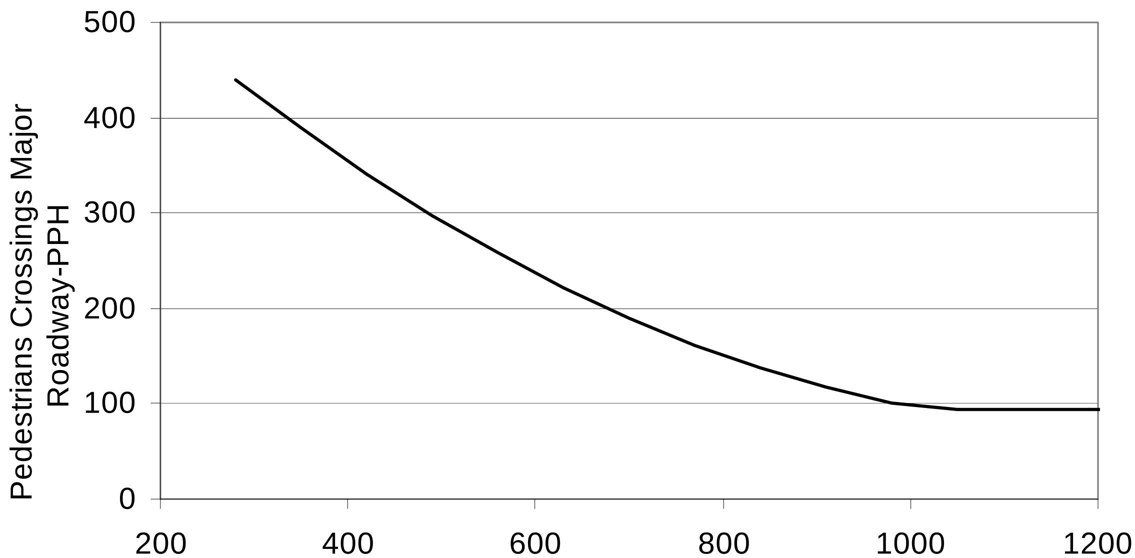
Figure B-3. Proposed MUTCD Figure 4C-6. Warrant 4, Peak Hour



*Note: 133 pph applies as the lower threshold volume.

Figure B-4. Proposed MUTCD Figure 4C-7. Warrant 4, Peak Hour (70% Factor)

Community less than 10,000 population or above 55 km/h or above 35 mph on major street or where a major transit stop is present



*Note: 93 pph applies as the lower threshold volume.

PROPOSED CHANGE II – ADD ALTERNATIVE

Following is a reproduction of the *MUTCD* section with the recommended addition to the *MUTCD* shown with an underline.

Section 4B.04 Alternatives to Traffic Control Signals

Guidance:
Since vehicular delay and the frequency of some types of crashes are sometimes greater under traffic signal control than under STOP sign control, consideration should be given to providing alternatives to traffic control signals even if one or more of the signal warrants has been satisfied.

Option:
These alternatives may include, but are not limited to, the following:

A. Installing signs along the major street to warn road users approaching the intersection;
B. Relocating the stop line(s) and making other changes to improve the sight distance at the intersection;
C. Installing measures designed to reduce speeds on the approaches;
D. Installing a flashing beacon at the intersection to supplement STOP sign control;
E. Installing flashing beacons on warning signs in advance of a STOP sign controlled intersection on major- and/or minor-street approaches;
F. Adding one or more lanes on a minor-street approach to reduce the number of vehicles per lane on the approach;
G. Revising the geometrics at the intersection to channelize vehicular movements and reduce the time required for a vehicle to complete a movement, which could also assist pedestrians;
H. <u>Revising the geometrics at the intersection to add a pedestrian median refuge island(s) and/or a curb extension;</u>
I. Installing roadway lighting if a disproportionate number of crashes occur at night;
J. Restricting one or more turning movements, perhaps on a time-of-day basis, if alternate routes are available;
K. If the warrant is satisfied, installing multiway STOP sign control;
L. Installing a roundabout intersection; and
M. Employing other alternatives, depending on conditions at the intersection.

PROPOSED CHANGE III – ADD PEDESTRIAN BEACON

Following is a reproduction of the *MUTCD* sections with strike-outs and underlines showing recommended changes to the *MUTCD*.

CHAPTER 4M. TRAFFIC CONTROL BEACONS FOR PEDESTRIANS

Section 4M.01 Application of Pedestrian Beacons

Support:

A pedestrian beacon is a special highway traffic signal used at some locations for pedestrians waiting to cross or crossing the street.

Option:

A pedestrian beacon may be considered for installation at a location that does not meet other traffic signal warrants to facilitate pedestrian crossings.

Guidance:

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 pedestrians to cross, or if the speed for vehicles approaching on the major street is too high to permit pedestrians to cross, or if pedestrian delay is excessive, installing a pedestrian beacon should be considered.

If one of the signal warrants of Chapter 4C is met and a traffic control signal is justified by an engineering study, and if a decision is made to install a traffic control signal, it should be installed based upon the provisions of Chapter 4D.

Standard:

If used, pedestrian beacons shall be used in conjunction with signs and pavement markings to warn and control traffic at midblock locations where pedestrians enter or cross a street or highway. A pedestrian beacon shall only be installed at a marked midblock crosswalk.

Section 4M.02 Design of Pedestrian Beacons

Standard:

Except as specified in this Section, a pedestrian beacon shall meet the requirements of this Manual.

A pedestrian beacon shall consist of three signal sections, with a CIRCULAR YELLOW signal lens centered below two horizontally aligned CIRCULAR RED signal lenses (see Figure 4M-1).

If the criteria described in the third paragraph of Section 4M.01 is met and a pedestrian beacon is justified by an engineering study, then:

A. At least two pedestrian beacons shall be installed for each approach of the major street, and
B. A stop line shall be installed for each approach of the major street, and
C. A pedestrian signal head conforming to the provisions set forth in Chapter 4E shall be installed at each end of the marked crosswalk, and
D. The pedestrian beacon shall be pedestrian actuated.

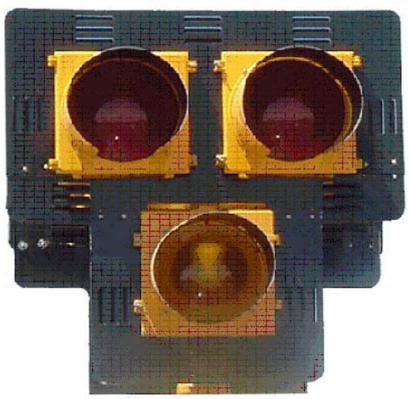
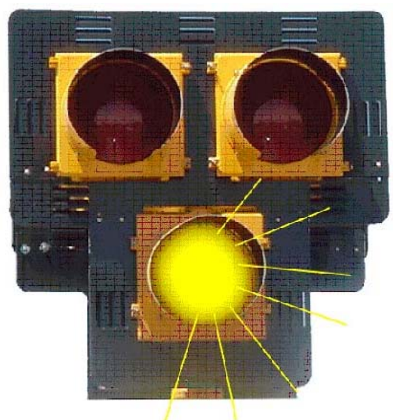
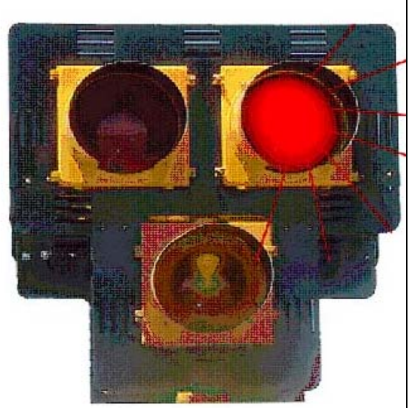
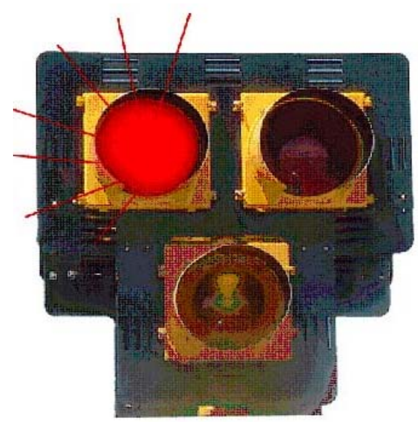
		
Dark Until Activated	Flashing Yellow for 3 to 6 sec	Steady Yellow for 3 to 6 sec
		
Steady Red during Pedestrian Walk Interval	Alternating Flashing Red During Pedestrian Clearance Interval	

Figure B-5. Proposed MUTCD Figure 4M-1. Example of Sequence for a Pedestrian Beacon.

Guidance:

If the criteria described in the third paragraph of Section 4M.01 is met and a pedestrian beacon is justified by an engineering study, then:

A. Parking and other sight obstructions should be prohibited for at least 30 m (100 ft) in advance of and at least 6.1 m (20 ft) beyond the marked crosswalk,

B. The installation should include suitable standard signs and pavement markings, and

C. If installed within a signal system, the pedestrian beacon should be coordinated.

Option:

Pedestrian beacons may be located over the roadway or adjacent to each side of the roadway at a suitable location.

Guidance:

On approaches having posted speed limits or 85th-percentile speeds in excess of 60 km/h (35 mph) and on approaches having traffic or operating conditions that would tend to obscure visibility of roadside beacon locations, at least one of the pedestrian beacons should be installed over the roadway.

On multilane approaches having posted speed limits or 85th-percentile speeds of 60 km/h (35 mph) or less, either a pedestrian beacon should be installed on each side of the approach (if a median of sufficient width exists) or at least one of the pedestrian beacons should be installed over the roadway.

A pedestrian beacon should comply with the signal face provisions described in Sections 4D.15 and 4D.17.

Standard:

A CROSSWALK STOP ON RED (symbolic red ball) (R10-23) sign shall be mounted adjacent to a signal face on each major street approach (see Section 2B.45). If an overhead signal face is provided, the sign shall be mounted adjacent to the overhead signal face.

Option:

A Pedestrian (W11-2) sign (see Section 2C.41) with an AHEAD (W16-9p) supplemental plaque may be placed in advance of a pedestrian beacon. A warning beacon may be installed to supplement the W11-2 sign and may be programmed to only flash during the yellow and red signal indications of the pedestrian beacon.

Standard:

If a warning beacon is installed to supplement the W11-2 sign, the design and location of the beacon shall conform to the provisions of Sections 4K.01 and 4K.03.

Section 4M.03 Operation of Pedestrian Beacons

Standard:

Pedestrian beacons shall be dark (not illuminated) during periods between actuations.

Upon actuation by a pedestrian, a pedestrian beacon shall display a flashing CIRCULAR YELLOW signal indication, followed by a steady CIRCULAR YELLOW signal indication, followed by both steady CIRCULAR RED signal indications during the pedestrian walk interval, followed by alternating flashing CIRCULAR RED signal indications during the pedestrian clearance interval (see Figure 4M-1). Upon termination of the pedestrian clearance interval, the pedestrian beacon shall revert to a non-illuminated condition.

The pedestrian signal heads shall continue to display a steady UPRAISED HAND (symbolizing DONT WALK) signal indication when the pedestrian beacon is displaying a flashing or steady CIRCULAR YELLOW signal indication. The pedestrian signal heads shall display a WALKING PERSON (symbolizing WALK) signal indication when the pedestrian beacon is displaying a steady CIRCULAR RED signal indication. The pedestrian signal heads shall display a flashing UPRAISED HAND (symbolizing DONT WALK) signal indication when the pedestrian beacon is displaying alternating flashing CIRCULAR RED signal indications. Upon termination of the pedestrian clearance interval, the pedestrian signal heads shall revert to a steady UPRAISED HAND (symbolizing DONT WALK) signal indication.

Guidance:

The duration of the flashing yellow interval should be determined by engineering judgment.

The steady yellow interval should have a duration of approximately 3 to 6 seconds (see Section 4D.10). The longer intervals should be reserved for use on approaches with higher speeds.

Section 4A.01 Types

Support:

The following types and use of highway traffic signals are discussed in Part 4: traffic control signals, pedestrian control features ~~signals~~, emergency-vehicle traffic control signals, traffic control signals for one-lane, two-way facilities; traffic control signals for freeway entrance ramps, traffic control signals for movable bridges; lane-use control signals; flashing beacons; ~~and~~ in-roadway lights; and pedestrians beacons.

4A.02 Definitions Relating to Highway Traffic Signals

Standard:
The following technical terms, when used in Part 4, shall be defined as follows:

1. Accessible Pedestrian Signal—a device that communicates information about pedestrian timing in nonvisual format such as audible tones, verbal messages, and/or vibrating surfaces.
2. Active Grade Crossing Warning System—the flashing-light signals, with or without warning gates, together with the necessary control equipment used to inform road users of the approach or presence of trains at highway-rail grade crossings or highway-light rail transit grade crossings.
3. Actuated Operation—a type of traffic control signal operation in which some or all signal phases are operated on the basis of actuation.
4. Actuation—initiation of a change in or extension of a traffic signal phase through the operation of any type of detector.
5. Approach—all lanes of traffic moving towards an intersection or a midblock location from one direction, including any adjacent parking lane(s).
6. Average Day—a day representing traffic volumes normally and repeatedly found at a location, typically a weekday when volumes are influenced by employment or a weekend day when volumes are influenced by entertainment or recreation.
7. Backplate—see Signal Backplate.
8. Beacon—a highway traffic signal with one or more signal sections that operates in a flashing mode.
9. Conflict Monitor—a device used to detect and respond to improper or conflicting signal indications and improper operating voltages in a traffic controller assembly.
10. Controller Assembly—a complete electrical device mounted in a cabinet for controlling the operation of a highway traffic signal.
11. Controller Unit—that part of a controller assembly that is devoted to the selection and timing of the display of signal indications.
12. Crosswalk—(a) that part of a roadway at an intersection included within the connections of the lateral lines of the sidewalks on opposite sides of the highway measured from the curbs or in the absence of curbs, from the edges of the traversable roadway, and in the absence of a sidewalk on one side of the roadway, the part of a roadway included within the extension of the lateral lines of the sidewalk at right angles to the centerline; (b) any portion of a roadway at an intersection or elsewhere distinctly indicated as a pedestrian crossing by lines on the surface, which may be supplemented by a contrasting pavement texture, style, or color.
13. Cycle Length—the time required for one complete sequence of signal indications.
14. Dark Mode—the lack of all signal indications at a signalized location. (The dark mode is most commonly associated with power failures, ramp meters, beacons, and some movable bridge signals.)

15. Detector—a device used for determining the presence or passage of vehicles or pedestrians.
16. Dual-Arrow Signal Section—a type of signal section designed to include both a yellow arrow and a green arrow.
17. Emergency Vehicle Traffic Control Signal—a special traffic control signal that assigns the right-of-way to an authorized emergency vehicle.
18. Flasher—a device used to turn highway traffic signal indications on and off at a repetitive rate of approximately once per second.
19. Flashing—an operation in which a highway traffic signal indication is turned on and off repetitively.
20. Flashing Mode—a mode of operation in which at least one traffic signal indication in each vehicular signal face of a highway traffic signal is turned on and off repetitively.
21. Full-Actuated Operation—a type of traffic control signal operation in which all signal phases function on the basis of actuation.
22. Highway Traffic Signal—a power-operated traffic control device by which traffic is warned or directed to take some specific action. These devices do not include signals at toll plazas, power-operated signs, illuminated pavement markers, warning lights (see Section 6F.78), or steady-burning electric lamps.
23. In-Roadway Lights—a special type of highway traffic signal 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.
24. Intersection—(a) the area embraced within the prolongation or connection of the lateral curb lines, or if none, the lateral boundary lines of the roadways of two highways that join one another at, or approximately at, right angles, or the area within which vehicles traveling on different highways that join at any other angle might come into conflict; (b) the junction of an alley or driveway with a roadway or highway shall not constitute an intersection.
25. Intersection Control Beacon—a beacon used only at an intersection to control two or more directions of travel.
26. Interval—the part of a signal cycle during which signal indications do not change.
27. Interval Sequence—the order of appearance of signal indications during successive intervals of a signal cycle.
28. Lane-Use Control Signal—a signal face displaying signal indications to permit or prohibit the use of specific lanes of a roadway or to indicate the impending prohibition of such use.
29. Lens—see Signal Lens.
30. Louver—see Signal Louver.
31. Major Street—the street normally carrying the higher volume of vehicular traffic.
32. Malfunction Management Unit—same as Conflict Monitor.
33. Minor Street—the street normally carrying the lower volume of vehicular traffic.
34. Movable Bridge Resistance Gate—a type of traffic gate, which is located downstream of the movable bridge warning gate, that provides a physical deterrent to vehicle and/or pedestrian traffic when placed in the appropriate position.
35. Movable Bridge Signal—a highway traffic signal installed at a movable bridge to notify traffic to stop during periods when the roadway is closed to allow the bridge to open.

36. Movable Bridge Warning Gate—a type of traffic gate designed to warn, but not primarily to block, vehicle and/or pedestrian traffic when placed in the appropriate position.
37. Pedestrian Change Interval—an interval during which the flashing UPRAISED HAND (symbolizing DONT WALK) signal indication is displayed. When a verbal message is provided at an accessible pedestrian signal, the verbal message is “wait.”
38. Pedestrian Clearance Time—the time provided for a pedestrian crossing in a crosswalk, after leaving the curb or shoulder, to travel to the far side of the traveled way or to a median.
39. Pedestrian Signal Head—a signal head, which contains the symbols WALKING PERSON (symbolizing WALK) and UPRAISED HAND (symbolizing DONT WALK), that is installed to direct pedestrian traffic at a traffic control signal.
40. Pedestrian Beacon—a special highway traffic signal used at some locations for pedestrians waiting to cross or crossing the street.
41. Permissive Mode—a mode of traffic control signal operation in which, when a CIRCULAR GREEN signal indication is displayed, left or right turns are permitted to be made after yielding to pedestrians and/or oncoming traffic.
42. Platoon—a group of vehicles or pedestrians traveling together as a group, either voluntarily or involuntarily, because of traffic signal controls, geometrics, or other factors.
43. Preemption Control—the transfer of normal operation of a traffic control signal to a special control mode of operation.
44. Pretimed Operation—a type of traffic control signal operation in which none of the signal phases function on the basis of actuation.
45. Priority Control—a means by which the assignment of right-of-way is obtained or modified.
46. Protected Mode—a mode of traffic control signal operation in which left or right turns are permitted to be made when a left or right GREEN ARROW signal indication is displayed.
47. Pushbutton—a button to activate pedestrian timing.
48. Pushbutton Locator Tone—a repeating sound that informs approaching pedestrians that they are required to push a button to actuate pedestrian timing and that enables pedestrians who have visual disabilities to locate the pushbutton.
49. Ramp Control Signal—a highway traffic signal installed to control the flow of traffic onto a freeway at an entrance ramp or at a freeway-to-freeway ramp connection.
50. Ramp Meter—see Ramp Control Signal.
51. Red Clearance Interval—an optional interval that follows a yellow change interval and precedes the next conflicting green interval.
52. Right-of-Way (Assignment)—the permitting of vehicles and/or pedestrians to proceed in a lawful manner in preference to other vehicles or pedestrians by the display of signal indications.
53. Roadway Network—a geographical arrangement of intersecting roadways.
54. Semiactuated Operation—a type of traffic control signal operation in which at least one, but not all, signal phases function on the basis of actuation.
55. Separate Left-Turn Signal Face—a signal face for controlling a left-turn movement that sometimes displays a different color of circular signal indication than the adjacent through signal faces display.

56. Shared Left-Turn Signal Face—a signal face, for controlling both a left turn movement and the adjacent through movement, that always displays the same color of circular signal indication that the adjacent through signal face or faces display.
57. Signal Backplate—a thin strip of material that extends outward from and parallel to a signal face on all sides of a signal housing to provide a background for improved visibility of the signal indications.
58. Signal Coordination—the establishment of timed relationships between adjacent traffic control signals.
59. Signal Face—that part of a traffic control signal provided for controlling one or more traffic movements on a single approach.
60. Signal Head—an assembly of one or more signal sections.
61. Signal Housing—that part of a signal section that protects the light source and other required components.
62. Signal Indication—the illumination of a signal lens or equivalent device.
63. Signal Lens—that part of the signal section that redirects the light coming directly from the light source and its reflector, if any.
64. Signal Louver—a device that can be mounted inside a signal visor to restrict visibility of a signal indication from the side or to limit the visibility of the signal indication to a certain lane or lanes, or to a certain distance from the stop line.
65. Signal Phase—the right-of-way, yellow change, and red clearance intervals in a cycle that are assigned to an independent traffic movement or combination of movements.
66. Signal Section—the assembly of a signal housing, signal lens, and light source with necessary components to be used for providing one signal indication.
67. Signal System—two or more traffic control signals operating in signal coordination.
68. Signal Timing—the amount of time allocated for the display of a signal indication.
69. Signal Visor—that part of a signal section that directs the signal indication specifically to approaching traffic and reduces the effect of direct external light entering the signal lens.
70. Signal Warrant—a threshold condition that, if found to be satisfied as part of an engineering study, shall result in analysis of other traffic conditions or factors to determine whether a traffic control signal or other improvement is justified.
71. Speed Limit Sign Beacon—a beacon used to supplement a SPEED LIMIT sign.
72. Steady (Steady Mode)—the continuous illumination of a signal indication for the duration of an interval, signal phase, or consecutive signal phases.
73. Stop Beacon—a beacon used to supplement a STOP sign, a DO NOT ENTER sign, or a WRONG WAY sign.
74. Traffic Control Signal (Traffic Signal)—any highway traffic signal by which traffic is alternately directed to stop and permitted to proceed.
75. Vibrotactile Pedestrian Device—a device that communicates, by touch, information about pedestrian timing using a vibrating surface.
76. Visibility-Limited Signal Face or Signal Section—a type of signal face or signal section designed (or shielded, hooded, or louvered) to restrict the visibility of a signal indication from the side, to a certain lane or lanes, or to a certain distance from the stop line.
77. Walk Interval—an interval during which the WALKING PERSON (symbolizing WALK) signal indication is displayed. When a verbal message is provided at an accessible pedestrian signal, the verbal message is "walk sign."

78. Warning Beacon—a beacon used only to supplement an appropriate warning or regulatory sign or marker.
79. Yellow Change Interval—the first interval following the green interval during which the yellow signal indication is displayed.

Section 2B.45 Traffic Signal Signs (R10-1 through R10-21)

Option:
To supplement traffic signal control, Traffic Signal signs R10-1 through R10-~~21~~ 23 may be used to regulate road users.

Guidance:
When used, Traffic Signal signs should be located adjacent to the signal face to which they apply.

Standard:
Traffic Signal signs applicable to pedestrian actuation (see Figure 2B-18) shall be mounted immediately above or incorporated in pedestrian pushbutton units (see Section 4E.08).

Support:
Traffic Signal signs applicable to pedestrians include:

A. CROSS ON GREEN LIGHT ONLY (R10-1);
B. CROSS ON WALK SIGNAL ONLY (R10-2);
C. PUSH BUTTON FOR GREEN LIGHT (R10-3); and
D. PUSH BUTTON FOR WALK SIGNAL (R10-4).

Option:
The following signs may be used as an alternate for the R10-3 and R10-4 signs:

A. TO CROSS STREET (arrow), PUSH BUTTON WAIT FOR GREEN LIGHT (R10-3a); and
B. TO CROSS STREET (arrow), PUSH BUTTON WAIT FOR WALK SIGNAL (R10-4a).

The symbol sign R10-2a may be used as an alternate to sign R10-2. Where symbol-type pedestrian signal indications are used, an educational sign (R10-3b) may be used to improve pedestrian understanding of pedestrian indications at signalized intersections. Where word-type pedestrian signal indications are being retained for the remainder of their useful service life, the legends WALK/DONT WALK may be substituted for the symbols on the educational sign R10-3b, thus creating sign R10-3c. The R10-3d sign may be used if the pedestrian clearance time is sufficient only for the pedestrian to cross to the median. The diagrammatic sign R10-4b may also be used as an alternate to sign R10-4. At intersections where pedestrians cross in two stages using a median refuge island, the word message “CROSS TO MEDIAN” may be placed on the near corner of the refuge island along with the educational plaque.

Traffic Signal signs (see Figure 2B-19) may be installed at certain locations to clarify signal control. Among the legends for this purpose are LEFT ON GREEN ARROW ONLY (R10-5), STOP HERE ON RED (R10-6 or R10-6a) for observance of stop lines, DO NOT BLOCK INTERSECTION (R10-7) for avoidance of traffic obstructions, USE LANE(S) WITH GREEN ARROW (R10-8) for obedience to Lane Control signals, LEFT TURN YIELD ON GREEN (symbolic green ball) (R10-12), and LEFT TURN SIGNAL YIELD ON GREEN (symbolic green ball) (R10-21) (see Section 4D.06).

In situations where traffic control signals are coordinated for progressive timing, the Traffic Signal Speed (I1-1) sign may be used (see Section 2D.47).

Standard:
The NO TURN ON RED (R10-11a, R10-11b) sign (see Figure 2B-19) shall be used to prohibit a right turn on red (or a left turn on red from a one-way street to a one-way street).

Option:
A symbolic NO TURN ON RED (R10-11) sign (see Figure 2B-19) may be used as an alternate to the R10-11a and R10-11b signs.

Guidance:
If used, the NO TURN ON RED sign should be installed near the appropriate signal head.

A NO TURN ON RED sign should be considered when an engineering study finds that one or more of the following conditions exists:

A. Inadequate sight distance to vehicles approaching from the left (or right, if applicable);
B. Geometrics or operational characteristics of the intersection that might result in unexpected conflicts;
C. An exclusive pedestrian phase;
D. An unacceptable number of pedestrian conflicts with right-turn-on-red maneuvers, especially involving children, older pedestrians, or persons with disabilities; and
E. More than three right-turn-on-red accidents reported in a 12-month period for the particular approach.

Where turns on red are permitted and the signal indication is a RED ARROW, the RIGHT (LEFT) ON RED ARROW AFTER STOP (R10-17a) sign (see Figure 2B-19) should be installed adjacent to the RED ARROW signal indication.

Option:
In order to remind drivers who are making turns to yield to pedestrians, especially at intersections where right turn on red is permitted and pedestrian crosswalks are marked, a TURNING TRAFFIC MUST YIELD TO PEDESTRIANS (R10-15) sign may be used (see Figure 2B-19).

A supplemental R10-20a plaque (see Figure 2B-19) showing times of day (similar to the S4-1 plaque shown in Figure 7B-1) with a black legend and border on a white background may be mounted below a NO TURN ON RED sign to indicate that the restriction is in place only during certain times.

Standard:
The EMERGENCY SIGNAL (R10-13) sign (see Figure 2B-19) shall be used in conjunction with emergency-vehicle traffic control signals (see Section 4F.02).

Standard:
The CROSSWALK STOP ON RED (symbolic red ball) (R10-23) sign (see Figure 2B-19) shall be used in conjunction with pedestrian beacons (see Chapter 4M).

Option:
A U-TURN YIELD TO RIGHT TURN (R10-16) sign (see Figure 2B-19) may be installed near the left-turn signal face if U-turns are allowed on a protected left-turn movement on an approach from which drivers making a right turn from the conflicting approach to their left are simultaneously being shown a right-turn GREEN ARROW signal indication.

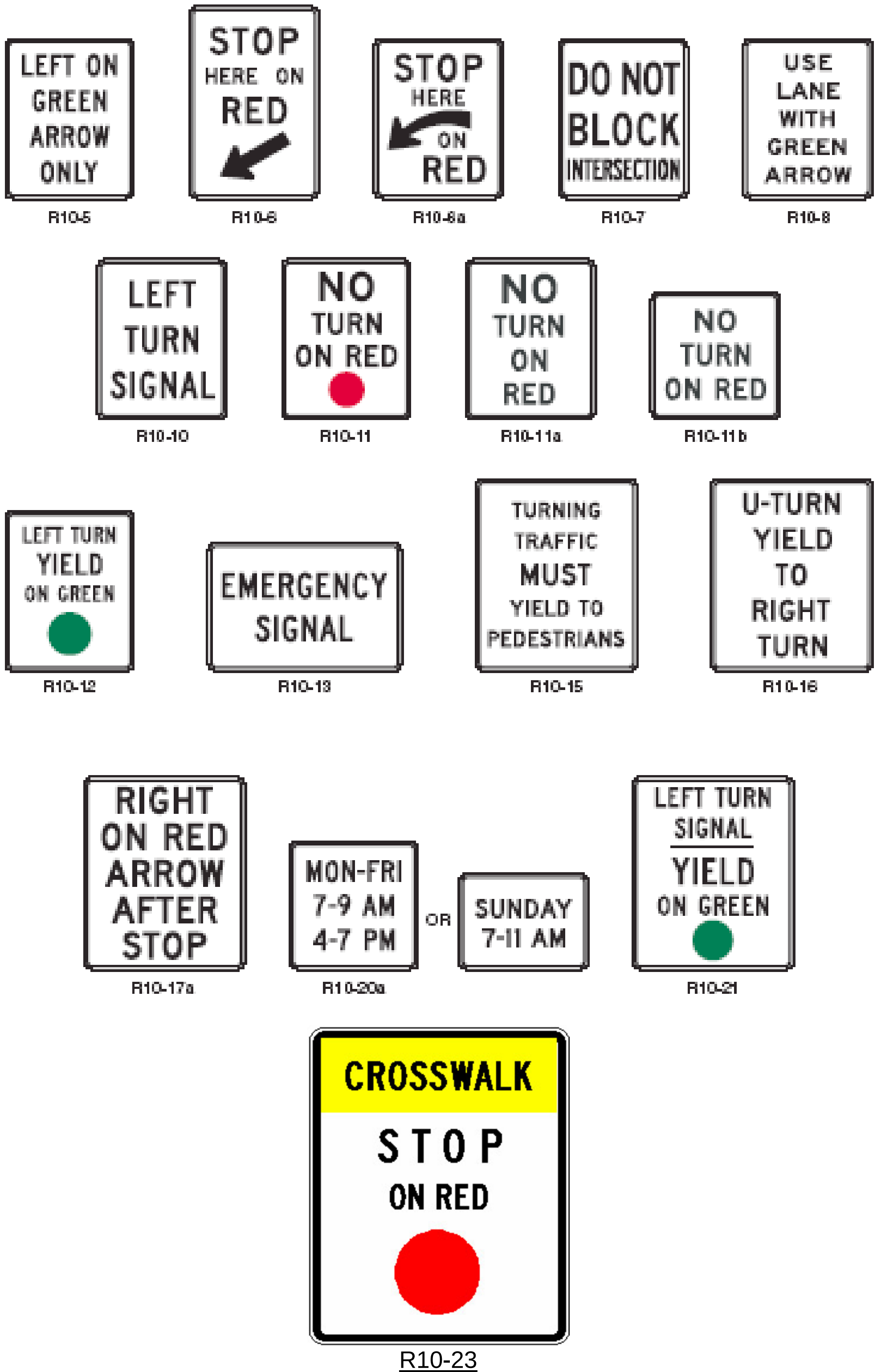


Figure B-6. Proposed MUTCD Figure 2B-19 Traffic Signal Signs.

APPENDIX C

LITERATURE REVIEW OF PEDESTRIAN CROSSING TREATMENTS AT UNCONTROLLED LOCATIONS

For this literature review, pedestrian crossing treatments are grouped into similar categories (as shown below) for ease of information presentation. In practice, several treatments or design elements may be combined at a single street crossing. For example, overhead flashing beacons may be used with a median refuge island and curb extensions. For evaluations in which several treatments were combined at a single location, the evaluation information is included in the section corresponding to the predominant treatment. If there is not a predominant treatment, then the evaluation information may be included in several sections corresponding to each treatment at that location. The basic categories of pedestrian crossing treatments (and some examples) as presented in this literature review are listed in Table C-1.

TABLE C-1. Basic Categories of Pedestrian Crossing Treatments.

Traffic Signal and Red Beacon Display

- Half-signal or adaptations (e.g., HAWK signal)
- Puffin/Pelican/Toucan pedestrian crossing signalization from Europe
- Automated pedestrian detection
- Educational plaques for walk signals
- Countdown indications

Signing and Marking

- Overhead flashing beacons
- In-roadway warning lights
- Flashing signs or beacons beside the crossing
- Motorist warning signs at or in advance of crossing
- Pedestrian warning signs at the crossing (e.g., "animated eyes," pavement text)
- Crosswalk pavement marking
- Text pavement markings
- Advance stop lines
- Pedestrian crossing flags

General Design

- Median refuge with angled or staggered pedestrian opening
- Landscaped median or fencing to discourage crossing at inappropriate location(s)
- No on-street parking in vicinity of crossing location
- Adequate street lighting
- Shortened curb radius for shorter crossing time
- Railing to direct pedestrians to appropriate crossing location(s)
- Curb extensions or bulb-outs
- Raised crosswalk or intersection

Enforcement

- Enforcement of motor vehicle yielding ("crosswalk sting")
- Enforcement of pedestrian crossing (jaywalk enforcement)
- Automated enforcement of red light running and/or speeding

TRAFFIC SIGNAL AND RED BEACON DISPLAY

Pedestrian crossing treatments in the signalization category include various types of pedestrian-specific signals or pedestrian elements that can be added to regular traffic signals. Examples include the following:

- Half-signal or adaptations (e.g., HAWK signal),
- Puffin/Pelican/Pussycat pedestrian crossing signalization from Europe, and
- Automated pedestrian detection.

Half-Signals or Adapted Half-Signals (e.g., HAWK)

The pedestrian signal (or half-signal) has been used in British Columbia, Canada, for over 25 years (*2*). Voss and Parks describe several operational and safety issues in a 2001 report and also document a study of half-signals in British Columbia. The operational and design characteristics of half-signals do vary among municipalities within British Columbia, which adds to the safety issues noted by the authors. For example, the typical half-signal consists of a regular traffic signal on the main street with stop control on the side street. The half-signal typically dwells in a flashing green ball mode until the pedestrian phase is activated, at which time a 5-second solid green indication is shown before the yellow and red intervals. However, several municipalities do not use the solid green indication. Other inconsistencies or design variations in British Columbia's half-signals include:

- Red flashing overhead signals are used at stop-controlled approaches.
- A painted crosswalk and pedestrian signal heads are often used on only one leg of the main street crossing.
- Vehicle and transit bus detectors are installed on the side street for actuation of the pedestrian phase for motorist and transit bus use.
- Pedestrian countdown timers are sometimes installed at the main street crossings.

Voss and Parks conducted a modest study of STOP sign compliance on side street approaches at 12 half-signal installations throughout the greater Vancouver area in the summer of 2000 (*2*). Despite including rolling stops as compliance, the authors found very low STOP sign compliance rates at nearly all half-signal installations. Only 2 of the 12 installations had STOP sign compliance rates above 90 percent, whereas the lowest compliance rate was 14 percent. The authors implied that the low STOP sign compliance was due in part to conflicting vehicle and pedestrian control at these half-signal installations.

City engineers in Tucson, Arizona, have made modifications to the basic half-signal design to develop what they refer to as a HAWK (<u>H</u>igh-intensity <u>A</u>ctivated cross<u>W</u>al<u>K</u>) signal (*3*, *4*). The HAWK crossing design utilizes a warning signal that is dark until activated by a pedestrian. Once activated, the HAWK signal flashes yellow then provides a solid red indication to vehicles and a WALK indication to pedestrians. An evaluation by the Highway Safety Research Center (HSRC) of the University of North Carolina (UNC) used two measures of effectiveness (MOEs): (1) the percent of motorists who yield to pedestrians and (2) the percent of pedestrians who hesitate before crossing, abort their crossing, or run while crossing. In a traditional before-and-after study, the evaluation of a single HAWK crossing found that motorist yielding increased from 31 to 93 percent. The percentage of hesitating, aborting, or rushed pedestrians decreased from 24 to 10 percent. The study site was a multilane divided arterial street with a posted speed limit of 40 mph (64 km/h). Before installation of the HAWK signal, the pedestrian crossing was delineated by advance and point-of-crossing pedestrian signs, a painted crosswalk, and advance pavement legends. Nassi noted the effectiveness of this type of treatment on wide, higher speed arterial streets (*3*).

Automated Pedestrian Detection

Automated pedestrian detection automatically detects waiting or crossing pedestrians and initiates a specific response, such as flashing beacons or extension of crossing time for WALK signals. Automated pedestrian detection is used because research has shown that pedestrians waiting to cross a street do not always activate pedestrian crossing pushbuttons. For example, a study by Zegeer et al. found that, on average, just half of all pedestrians use a pushbutton to cross streets (*5*). Another study in Cambridge, Massachusetts, indicated that as few as 10 percent of pedestrians used a pushbutton to cross low-volume streets (*6*). The study indicated that more pedestrians used the pushbutton on moderate- to high-volume streets, when it was necessary to get an exclusive pedestrian crossing phase.

A study by Hughes et al. evaluated the use of automated pedestrian detection in conjunction with standard pedestrian pushbuttons (*7*). The research team used two MOEs to determine if automated pedestrian detection could improve pedestrian safety: pedestrian-vehicle conflicts and inappropriate crossing behavior (i.e., crossing during the DON'T WALK signal). The detection devices (and corresponding technology) were installed at the following locations:

- Los Angeles, California: one intersection, both infrared and microwave;
- Rochester, New York: two intersections, microwave; and
- Phoenix, Arizona: one intersection, microwave.

This study found that the use of automated pedestrian detection reduced pedestrian-vehicle conflicts by the following amounts: (1) 89 percent for the first half of the street crossing, (2) 42 percent for the second half of the street crossing, (3) 40 percent for right-turning vehicles, and (4) 76 percent for other types of conflicts. The study also found an overall 24 percent increase in the pedestrians who began to cross during the WALK signal and an overall 81 percent decrease in the pedestrians who began to cross during the steady DON'T WALK signal. The authors also noted some difficulties in tuning the detection devices to avoid false and missed detections.

Several technologies automatically detect pedestrians: passive infrared, ultrasonic, Doppler radar, video imaging, and pressure-sensitive (piezometric) mats. Beckwith and Hunter-Zaworski evaluated the first three technologies listed above and reported on their effectiveness in passively detecting pedestrians (*8*). Preliminary tests of the three devices produced positive detection rates that varied from 47 to 96 percent, with all devices above 89 percent detection once they had been optimally positioned and tuned. The Doppler radar and infrared devices were combined into a single installation for long-term testing. Initial results from this long-term testing site indicate that 100 percent of pedestrians (in 60 pedestrian crossings) were detected. One issue noted was that the activated device, flashing beacons in this case, remained activated for nearly twice as long as the time pedestrians needed to cross. The authors indicated that passing vehicles from high-volume traffic may have kept the flashing beacons activated longer than required.

Pedestrian Countdown Indication

Pedestrian countdown indications provide pedestrians with a descending numerical countdown of the flashing hand clearance interval. It indicates to the pedestrian the time available for their crossing. The device was installed on one leg of an intersection in Hampton, Virginia. The results found after 24 months of experience that 88 percent of pedestrians feel that the new pedestrian signals are clearer than the conventional displays and 82 percent feel that the new pedestrian heads are an improvement (*9*). A 1999 study at two locations in Monterey, California surveyed pedestrians after they had crossed the intersection (*10*). The interviews indicated that the countdown signals were easily understood by all age groups. A large majority of pedestrians felt safer knowing the remaining crossing time and indicated that the device was a welcome added feature. The researchers also found that pedestrians did not attempt to cross when less than 10 to 6 seconds remained on the display (depending upon which intersection they were crossing). Another study in Minnesota that included market research at five intersections also found that pedestrians do understand the countdown pedestrian indication and use the information appropriately and well (*11*).

A Florida DOT study evaluated the effects of countdown signals. The study evaluated two intersections with the treatments and compared the findings to three control intersections that were similar but did not have countdown signals (*12*). The countdown signals had the positive effect (compared to sites without countdown signals) of reducing the number of pedestrians who started running when the flashing DON’T WALK signal appeared. They had the undesired effect of reducing compliance with the WALK signal (i.e., more pedestrians began their crossing during the flashing or steady DON’T WALK). There was no effect on the number of persons who ran out of time while crossing.

Pedestrian countdown signals were evaluated in San Jose, California, in 2001-2002 at four intersections/crossings (*13*). In addition, two comparative sites were also included in the study. The performance of the signals was assessed with operations studies, pedestrian surveys, conflict analysis, and a review of crash data. Similar to the Florida DOT study, this study found that the percentage of pedestrians entering the intersection during the flashing DON’T WALK signal increased. They also found that the proportions of pedestrians exiting on the DON’T WALK signal decreased, which they attributed to pedestrians using the information on the timer to adjust their walking speeds in order to clear the intersection before the DON’T WALK phase. Their observations of motorist signal violations (entering in yellow or red) showed no discernable negative effect from the installation of the signal.

SIGNING AND PAVEMENT MARKING

There are numerous crossing treatments that are grouped into the signing and marking category. The most common examples include:

- Overhead flashing beacons,
- In-roadway warning lights,
- Flashing signs or beacons beside the crossing,
- Motorist warning signs at or in advance of crossing,
- Pedestrian warning signs at the crossing (e.g., “animated eyes,” pavement text), and
- Crosswalk pavement markings.

Multiple Treatments

A study team led by the Center for Urban Transportation Research (CUTR) of the University of South Florida evaluated numerous pedestrian crossing treatments in St. Petersburg, Florida (*14*). The study evaluated the effects of engineering treatments in a program that used education, enforcement, and engineering (3E) components at both signalized and unsignalized intersections. The engineering treatments used include:

- Advance stop/yield lines,
- Lead pedestrian intervals (signalized intersections only),
- Scanning eyes on pedestrian signal heads (signalized intersections only),
- Flashing amber beacons with pedestrian signal (with passive pedestrian detection),
- Half-signals, and
- Pedestrian and motorist prompting signs.

Motor vehicle yielding behavior and pedestrian-motor vehicle conflicts were the primary measures used in evaluating the treatments. Because of the 3E components of the pedestrian safety campaign, it is difficult to decisively attribute post-installation changes to specific program elements (such as the engineering treatments only). Despite this difficulty, the study authors reported that the engineering treatments provided little improvement in vehicle yielding at signalized intersections (from 60 to 62 percent, on average) but found some improvement at unsignalized intersections (3 to 24 percent). The evaluation results for changes in vehicle conflicts were similar. For signalized intersections, pedestrians experiencing conflicts remained nearly unchanged, from 3 to 4 percent. However, for signalized intersections, pedestrians experiencing conflicts decreased from 4 to 0.3 percent. The study found that the largest improvements were realized when implementing multiple treatments that prompted both motor vehicle and pedestrian awareness.

The study authors indicated that the greatest improvements were obtained with the half-signal installation, which also included advance stop lines and motorist prompting signs. At this study site, motorist yielding increased from 3 to 100 percent. Additionally, pedestrians experiencing conflicts decreased from 4 to 0 percent. This was the only study site to achieve a motorist yielding rate greater than 70 percent. The next most effective installation employed multiple treatments: flashing amber beacons, advance stop lines, motorist prompting signs, and special crosswalk markings. At this study site, motorist yielding increased from 3 to 30 percent, while the pedestrian conflicts dropped from 2 to 0.5 percent.

The city of Los Angeles, California, has developed what they refer to as a "Smart Pedestrian Warning" system that includes multiple pedestrian crossing treatments (*15*):

- Advance pavement messages ("PED XING"),
- Advance warning pedestrian signs,
- Extended red curb,
- Double posting of intersection pedestrian signs,
- Ladder-style crosswalk markings,
- Automated pedestrian detection (video imaging), and
- Actuated alternating flashing overhead amber beacons.

This pedestrian crossing design and its various elements have evolved over the past several years based on experimentation and testing. To date, about 25 pedestrian crossing warning systems have been installed in Los Angeles. Fisher reports on informal evaluations by city engineering staff, which indicate that this pedestrian warning system has improved motorist yielding to pedestrians from 20 to 30 percent to the 72 to 76 percent range. Their evaluation also indicates that, of the 24 to 28 percent of motorists who do not yield, at least they travel more slowly when approaching the enhanced crossings. For example, limited data indicate that 85th percentile vehicle speeds are reduced from 2 to 12 mph (3.2 to 19.3 km/h).

Flashing Signals or Beacons

An overhead beacon and crosswalk sign was evaluated in Seattle, Washington, by the HSRC research team. The treatment consisted of a large internally illuminated yellow sign reading "CROSSWALK" with flashing amber beacons on each side (*2*). After installation of this treatment, motorist yielding to pedestrians increased from 46 to 52 percent. Pedestrians running, hesitating, or aborting their crossing deceased from 58 to 43 percent. The study noted that driver compliance could be further improved by using actuated flashing beacons (i.e., activated by the pedestrian or a pedestrian-sensing device).

Van Winkle and Neal evaluated the use of pedestrian-actuated advance and crosswalk flashers in Chattanooga, Tennessee (*16*). The installation of the crosswalk flashers was a compromise solution for a group of senior citizens that demanded a traffic signal so that they could cross a minor arterial street with speed limit of 40 mph (64.4 km/h). City staff conducted a before-and-after study in 1987, with follow-up data collection in 2000. The evaluation collected data on the percentage of drivers yielding or slowing at the pedestrian crosswalk. The original 1987 data collection showed that driver yielding improved from 11 to 52 percent in the eastbound direction and 6 to 32 percent in the westbound direction. The percentage of drivers yielding at this location has been sustained as a long-term improvement, as driver yielding in 2000 was measured to be 55 percent in the eastbound direction and 45 percent in the westbound direction. The authors attribute the success of the flashers to pedestrian actuation. The city of Chattanooga has installed similar flashing crosswalk warning devices at three other locations with what they characterize as similar results, although no formal studies of their effectiveness have been conducted.

Sparks and Cynecki report on the use of flashing beacons for warning of pedestrian crosswalks in Phoenix, Arizona (*17*). The city evaluated the application of advance warning flashing beacons at four pedestrian crossing locations. The authors describe the use of several experiments in their evaluation, including before-and-after speed and crash data collection as well as treatment-and-control experiments for traffic speeds. The authors found that the advance warning flashing beacons did not decrease speeds or crashes, and in some cases the traffic speeds or crashes increased after installation of the flashing beacons. These findings led the authors to conclude "that flashers offer no benefit for intermittent pedestrian crossings in an urban environment. In addition, the longer the flashers operate the more it becomes part of the scenery and loses any effectiveness." The authors do concede that actuated warning flashers may be beneficial in a high-speed rural environment with unusual geometrics, high pedestrian crossings, and unfamiliar drivers. However, these conditions were not tested in their study.

In-Roadway Warning Lights at Crosswalks

In-roadway warning lights have been evaluated in numerous studies with varying results. It appears that the effectiveness of this treatment varies widely depending upon the characteristics of the site and existing motorist and pedestrian behavior. The following paragraphs describe results from numerous evaluations of in-roadway warning lights.

Whitlock and Weinberger Transportation, Inc., summarize the evaluation results of in-roadway warning lights at numerous locations in California (*18*). In these installations, the in-roadway warning lights were supplemented with a pedestrian crosswalk sign with warning amber light-emitting diode (LED) lights, as well as a pedestrian-activated pushbutton with flashing LEDs and "CROSS WITH CAUTION" sign. Two different MOEs are used to report evaluation results: (1) percentage of motorists yielding to pedestrians and (2) advanced vehicle braking distance. These MOEs are shown in Table C-2 for both daytime and nighttime conditions. For all six study sites, the percentage of motorists yielding to pedestrians increased. The improvements in motorist yielding behavior were typically much greater for nighttime conditions. The changes with advanced vehicle braking distance showed similar results, with improvements (increases) to braking distance being greater during nighttime conditions.

The city of Kirkland, Washington, installed in-roadway warning lights at two midblock locations in the fall of 1997 (*19*). Whitlock and Weinberger Transportation, Inc., evaluated the crossing treatments at these locations and reported the results using the same two MOEs as the California study: (1) percentage of motorists yielding to pedestrians and (2) advanced vehicle braking distance. The evaluation results are shown in Table C-3. The evaluation team found improvements to both MOEs after installation, with more dramatic improvements evident during nighttime tests. Before installation, driver yielding ranged from 16 to 65 percent. After installation of the in-roadway warning lights, driver yielding ranged from 85 to 100 percent. The study found that "the concept of amber flashing lights embedded in the pavement at uncontrolled crosswalks clearly has a positive effect in enhancing a driver's awareness of crosswalks and modifying driving habits to be more favorable to pedestrians."

TABLE C-2. Evaluation Results of In-Roadway Warning Lights in California (*18*).

Location	Percentage of motorists yielding to pedestrians				Advanced vehicle braking distance (ft)			
	Daytime		Nighttime		Daytime		Nighttime	
	Before	After	Before	After	Before	After	Before	After
Summerfield Road, Santa Rosa, CA	25	64	1	87	152	220	187	268
Main Street, Fort Bragg, CA	47	85	11	95	106	142	90	216
Mt. Diablo Blvd., Lafayette, CA	6	21	1	53	130	127	93	174
Pleasant Hill Road, Lafayette, CA	8	32	2	39	173	210	201	318
Petaluma Blvd. S., Petaluma, CA	68	87	56	83	99	119	97	123
JFK University, Orinda, CA	18	23	16	31	115	104	122	146
Main Street, Willits, CA	26	61	6	66	170	193	141	228
Unweighted Average	**28**	**53**	**13**	**65**	**135**	**159**	**133**	**210**

TABLE C-3. Evaluation Results of In-Roadway Warning Lights in Kirkland, Washington (*19*).

Location	Percentage of motorists yielding to pedestrians				Advanced vehicle braking distance (ft)			
	Daytime		Nighttime		Daytime		Nighttime	
	Before	After	Before	After	Before	After	Before	After
Central Way Eastbound	62	92	16	100	200	278	115	238
Central Way Westbound	59	94	27	98	192	244	175	270
NE 124th Street Eastbound	46	85	65	93	209	214	204	244
NE 124th Street Westbound	55	92	48	97	271	312	266	304
Unweighted Average	**56**	**91**	**39**	**97**	**218**	**262**	**190**	**264**

Boyce and Van Derlofske compared the effectiveness of in-roadway warning lights to basic crosswalk markings at a single location with two crosswalks in Denville, New Jersey (*20*). The authors found that the in-roadway warning lights decreased the speed at which vehicles approached the crosswalk, but that this speed reduction diminished over time. Additionally, vehicle-pedestrian conflicts with the in-roadway warning lights also increased over time. The authors also reported several problems with this specific implementation of in-roadway warning lights. The passive detection of waiting or crossing pedestrians was considered inadequate, and the authors recommended other types of detection. Five of the ten in-roadway warning lights had to be replaced within a year of installation, and the lenses of the warning lights also required regular cleaning because of debris build-up. Snowplows also damaged several of the in-roadway warning lights. The authors consider the in-roadway warning lights (with some modifications) to be appropriate at unusual locations (e.g., midblock crossings) with a documented crash history.

Katz, Okitsu, and Associates prepared a study of in-roadway warning lights for Fountain Valley, California (*21*). Their study analyzed the reported safety record of approximately 30 treatment locations that have been in place for more than 1 year and compared it with the expected safety record for traditional crosswalk treatments. The in-roadway warning light system is not 100 percent effective in preventing motor vehicle-pedestrian crashes; however, the few accidents that have been reported may not have been susceptible to correction by the warning system. The system appears to have reduced the crash expectancy by 80 percent; however, it is not known whether this is a novelty effect or will continue over time. The study also found that marked crosswalks with in-roadway flashers had a lower crash rate than comparable marked crosswalks.

Huang et al. documented the evaluation of in-roadway warning lights at a single location in Orlando, Florida (*22*). The evaluation, which was conducted to determine the effects of the in-roadway warning lights on pedestrian and motorist behavior, collected both before-and-after and treatment-and-control data. The before-and-after data focused on vehicle speeds and vehicle yielding. The treatment-and-control data included: (1) pedestrian crossing locations relative to the in-roadway warning crosswalk, with and without police officers; (2) pedestrian-motor vehicle conflicts; (3) pedestrian activation of the flashing crosswalk; and (4) pedestrian interviews. The authors reported these results:

- Average vehicle speeds decreased by 1.9 mph (3.1 km/h) when a pedestrian was present and 0.8 mph (1.3 km/h) when no pedestrians were present, but the decreases were not significant.
- Vehicle yielding improved from 13 percent before to 34 percent (when flashers were activated) and 47 percent (when flashers were not activated). The authors could not explain why more drivers yielded when the flashers were not activated.
- About 28 percent of the pedestrians crossed in the flashing crosswalk when police officers were not present. The remaining 72 percent of pedestrians crossed elsewhere, depending on what was the most convenient path between their origins and destinations.
- Of the pedestrians who crossed in the flashing crosswalk, 40 percent did not experience any conflicts. This compared to 22 percent of those who crossed within 30 ft (9.2 m) and only 13 percent of those who crossed elsewhere. The researchers concluded that motorists were more likely to stop or slow for pedestrians who crossed in or near the flashing crosswalk than those who crossed elsewhere.

A subsequent study Huang evaluated in-roadway warning lights at one uncontrolled pedestrian crossing each in Gainesville and Lakeland, Florida (*23*). The evaluation used traditional before-and-after data collection and used these MOEs: (1) motorists yielding to pedestrians, (2) pedestrians who had the benefit of motorists yielding to them, (3) pedestrians who crossed at a normal walking speed, and (4) pedestrians who crossed in the crosswalk. The results for these MOEs were quite different between the two study sites. At the study site in Gainesville, driver yielding actually decreased from 81 to 75 percent. Although the decrease was significant, it was considered practically negligible because of site characteristics. At the Lakeland site driver yielding improved, in this case from 18 to 30 percent, a result that was reported as not statistically significant because of low sample sizes. The results from the other MOEs were not that informative, as major changes were not observed.

Prevedouros reported on the evaluation of in-roadway warning lights installed on a six-lane arterial street in Honolulu, Hawaii (*24*). The evaluation consisted of a traditional before-and-after study of traffic volumes, vehicle spot speeds, pedestrian crossing observations, and pedestrians' and motorists' perceptions of change in the situation. The author reported the following results:

- A 16 to 27 percent reduction in vehicle speeds was measured when the flashing lights were activated.
- The average pedestrian wait time at the curb decreased from 26 to 13 seconds, and the average crossing time decreased from 34 to 27 seconds. The crossing time decreased because pedestrians did not have to wait as long in the refuge island before crossing the second direction.
- The proportion of pedestrians who were observed to run during the crossing decreased from 22 to 12 percent after the flashing lights were installed. The proportion of pedestrians crossing outside the marked crosswalk also decreased from 16 to 8 percent after installation.

Motorist Warning Signs

Nitzburg and Knoblauch reported on the evaluation of an illuminated pedestrian crossing sign used in combination with a high-visibility ladder-style crosswalk marking (*25*). Four crossing locations in Clearwater, Florida, were evaluated with a treatment-and-control experimental design (before-and-after data collection was not possible because the treatments had already been installed). The authors reported a significant increase (30 to 40 percent) in daytime driver yielding behavior and a smaller (8 percent) and statistically insignificant increase in nighttime driver yielding behavior. A 35 percent increase in crosswalk usage by pedestrians was noted, along with no change in pedestrian overconfidence, running, or conflicts. The authors concluded that the high-visibility crosswalk treatments had a positive effect on pedestrian and driver behavior on the relatively narrow low-speed crossings that were studied. The paper indicated that additional work is needed to determine if these treatments will have as desirable an effect on wider, higher speed roadways.

Huang et al. evaluated three innovative pedestrian signing treatments at locations in Seattle, Washington; six sites in New York State; Portland, Oregon; and three sites in Tucson, Arizona (*26*). The three treatments evaluated were an overhead crosswalk sign, a pedestrian safety cone typically placed in the roadway, and an overhead flashing regulatory sign prompting motorists to stop for pedestrians in the crosswalk. The evaluation used traditional before-and-after data collection for three MOEs: (1) percentage of pedestrians for whom motorists yielded; (2) percent of pedestrians who ran, aborted, or hesitated; and (3) percent of pedestrians crossing in the crosswalk. The results of the study are shown in Table C-4 below. All treatments except the overhead flashing sign in Tucson showed improvements in motorist yielding. The authors indicated that the effectiveness of the flashing regulatory sign may have been limited because it was installed on four- and six-lane arterial streets with speed limits of 40 mph (64.4 km/h) (the other study locations were primarily two-lane streets with speed limits of 25 or 30 mph [40.2 or 48.3 km/h]).

TABLE C-4. Effectiveness of Pedestrian Treatments at Unsignalized Locations (*26*).

Study Location	Percent of pedestrians for whom motorists yielded	Percent of pedestrians who ran, aborted, or hesitated	Percent of pedestrians crossing in the crosswalk
Overhead CROSSWALK sign, (1 site in Seattle)	Before – 46 After – 52	Before – 58 After – 43	Before – 100 After – 100
In-roadway pedestrian safety cone (6 sites in New York, 1 site in Portland)	Before – 70 After – 81	Before – 35 After – 33	Before – 79 After – 82
Overhead flashing crosswalk regulatory sign (3 sites in Tucson)	Before – 63 After – 52	Before – 17 After – 10	Before – 94 After – 94

Advance Yield/Stop Line

Advance yield/stop lines and signs have been found to be most effective on multilane streets where “multiple-threat” crashes are most likely to occur. The principle behind the advance yield/stop line is that vehicles yielding 49 ft (15 m) back from the crosswalk are less likely to screen views of the crossing pedestrian from motorists in other lanes. Additionally, motorists may be less likely to pass yielding vehicles in the next lane of travel.

Several studies by Van Houten and others (*27*, *28*, *29*) have demonstrated the effectiveness of advance yield lines (i.e., pavement markings) and “YIELD HERE TO PEDESTRIAN” signs. This research found a marked reduction in motor vehicle-pedestrian conflicts and an increase in motorists yielding to pedestrians at multilane crosswalks with an uncontrolled approach. These results have been documented at crosswalks with and without amber flashing beacons. Van Houten and Malenfant (*28*) also demonstrated that the markings and sign together were more effective than the sign alone. In a recent study by Van Houten et al., advance yield lines and “YIELD HERE TO PEDESTRIAN” signs were shown to reduce vehicle-pedestrian conflicts by 67 to 87 percent (*29*). The study also found a large increase in the distance at which motorists yielded to pedestrians. These evaluation results were further replicated at 24 additional study sites.

"Animated Eyes" Display

Van Houten and others documented the effectiveness of animated or roving eyes in conjunction with overhead flashing amber beacons and automated pedestrian detection at a single location in St. Petersburg, Florida (*30*). The evaluation used a traditional before-and-after study approach with alternating treatments. The MOEs included driver yielding, pedestrian-vehicle conflicts, and pedestrians stranded in the center of the roadway. The installation of the animated LED eyes increased driver yielding from 15 to 62 percent, whereas the flashing beacon only increased yielding from 15 to 36 percent. Pedestrians stranded decreased from 17 to 6 percent for the flashing beacon and 3 percent for the animated LED eyes. The experimental design with alternating treatments could have produced some residual effects, as the animated LED eyes was tested one day and the flashing beacons could have been tested the very next day. It is not clear whether the authors addressed these residual effects in this study.

Crosswalk Pavement Markings

Zegeer et al. has performed the most authoritative study to date on the effectiveness of crosswalk pavement markings alone as a pedestrian crossing treatment at uncontrolled locations (*31*, *32*). This study indicated that crosswalk markings are appropriate for crossings with certain street characteristics, such as low traffic volumes and speeds or a limited number of lanes. The study indicates that as traffic volumes, speeds, and street width increase, crosswalk markings alone are associated with a greater crash frequency than no crosswalk markings. The study recommendations indicate that the issue should not be whether or not to provide crosswalk markings on these high-volume, high-speed streets. Instead, the recommendations point to the necessity of providing other treatments in addition to crosswalk markings that will provide a safer street crossing for pedestrians.

Koepsell et al. published a study of the effects of crosswalk markings on the risk of vehicle-pedestrian crashes involving older pedestrians (*33*). The study gathered crash data and other site characteristics (e.g., traffic and pedestrian volumes, traffic speed, signalization characteristics) from six cities in Washington State and California from 1995 to 1999. The study used a case-control design and compared 282 case sites to 564 control sites. After adjusting for the various traffic and pedestrian characteristics, the researchers found that the risk of a pedestrian-vehicle crash was 3.6 times greater at uncontrolled intersections with a marked crosswalk. These findings agree with those earlier findings of Herms in San Diego and of Zegeer et al. (*31*).

Knoblauch and Raymond reported on a study of the effects of pedestrian crosswalk markings on vehicle speeds (*34*) at six sites in Maryland, Virginia, and Arizona. The study used traditional before-and-after data collection, where the "before" condition was obtained on a resurfaced arterial street (35 mph [56.3 km/h] speed limit) that had centerline and edgeline delineation but no crosswalk markings. Staged pedestrians were used to evaluate reductions in vehicle speeds under three conditions: (1) pedestrian present, (2) pedestrian looking, and (3) pedestrian not looking. As indicated by the authors, the "results of this evaluation are not clear cut." In combining results from five of the six sites (one site had aberrant data), the crosswalk markings appear to have a very modest effect on vehicle speeds, decreasing them on average from 0.17 to 2.1 mph (0.28 to 3.32 km/h). However, the largest speed decrease of 2.1 mph (3.32 km/h) was measured when no pedestrians were present, implying that motorists slowed simply because of the presence of crosswalk markings. The other statistically significant speed decrease of 1.62 mph (2.61 km/h) was measured for the condition of pedestrian not looking. This result follows logically, as the authors hypothesized that vehicles would likely slow for pedestrians who appear ready to step onto the roadway without looking for traffic.

Jones and Tomcheck reported on a study of vehicle-pedestrian collisions at 104 intersections in Los Angeles, California, where marked crosswalks at uncontrolled intersections were not reinstalled after roadway resurfacing from February 1982 through December 1991 (*35*). The authors used a post hoc before-and-after study of pedestrian collision histories to document the effects of crosswalk removal. The crash history extended back to January 1979, so all before-and-after crash histories included at least 3 years of data for each case. In considering crashes at both marked and unmarked legs of the intersections at which the marked leg was removed, the authors found that the number of pedestrian-vehicle crashes declined from 116 to 31 for equivalent time periods, a 61 percent decline. At adjacent intersections where crosswalk markings were reinstalled after resurfacing, pedestrian-vehicle crashes increased slightly from 27 to 30, thus indicating that the reduction in crashes at removed crosswalks was not simply being transferred to adjacent marked crosswalks. The authors performed statistical significance testing and found the crash reductions at the removed crosswalks to be significant.

Knoblauch, Nitzburg, and Siefert reported on a study of the effects of pedestrian crosswalk markings on pedestrian and driver behavior (*36*). The study included 11 unsignalized intersections in four cities: Sacramento, California; Richmond, Virginia; Buffalo, New York; and Stillwater, Minnesota. The researchers considered the following behavior in the crosswalk markings evaluation:

- Pedestrian compliance to crossing location,
- Vehicle speeds,
- Vehicle yielding compliance, and
- Pedestrian behavior as related to level of caution.

The authors presented the following conclusions:

- Drivers appeared to drive slower when approaching a marked crosswalk. The speed reductions are modest (as shown in the previous Knoblauch study) but evident nonetheless. This finding implies that most motorists are aware of the pedestrian crossing.
- No changes in driver yielding behavior were observed after the installation of marked crosswalks. This result implies that motorists may be slowing down just in case they are forced to stop by a pedestrian stepping into the roadway.
- There were no changes in blatantly aggressive pedestrian behavior after installations of marked crosswalks, indicating that pedestrians do not feel overly protected by marked crosswalks.

- Overall, crosswalk usage increased after marked crosswalks were installed. The authors found that single pedestrians are more likely to use marked crosswalks than a group of pedestrians traveling together.

Gibby et al. analyzed pedestrian-vehicle crash data at 380 intersections on California state highways (*37*). The study found that crash rates at marked crosswalks were 3.2 to 3.7 percent higher than crash rates at unmarked crosswalks (after accounting for pedestrian exposure). This result corresponded to earlier work by Herms in San Diego, and also correlates to Zegeer's study in the late 1990s. The implication is that marked crosswalks ALONE are not sufficient on multilane streets with high traffic volumes and speeds.

A study by Hauck and Bates in the late 1970s examined pedestrian and motorist compliance with marked and unmarked crosswalks (*38*). The study concluded that there was a significant increase in pedestrian and motorist observance of crosswalks at 17 locations after these were marked.

In the late 1960s, Herms examined 5 years of crash experience at 400 unsignalized intersections in San Diego, California (*39*, *40*). The study found that nearly six times as many crashes occurred in marked crosswalks as in unmarked crosswalks. After accounting for crosswalk usage, the crash ratio was reduced to about three times as many crashes in marked crosswalks. Many have criticized this study as leading to the removal of pedestrian accommodation on city streets. Many now think that crosswalk markings should not be removed in these cases, but rather supplemented with various other types of safety treatments that enable pedestrians to cross busy roadways.

Pedestrian Warning Signs and Markings

Retting et al. describe the evaluation of pedestrian warning signs and markings at three signalized intersections (*41*). The warning sign and pavement marking prompted pedestrians to look for potential vehicle conflicts with the message "PEDESTRIANS: LOOK FOR TURNING VEHICLES." The evaluation used a before-and-after study design at two intersections in Dartmouth, Nova Scotia (Canada), and one intersection in Clearwater, Florida. The study also examined the effects of adding only one treatment initially and then adding the second treatment later. The primary MOEs used in the study were:

- Percentage of pedestrians that did not look for any threats,
- Percentage of pedestrians that did look for various threats, and
- Number of conflicts between pedestrians and turning vehicles.

The evaluation results indicated that the combination of a sign and pavement marking was generally more effective than only installing a single warning prompt. There did not appear to be any significant difference in the effectiveness of the treatments, although the pavement markings did yield slightly greater improvements in looking behavior. The results at individual sites are presented in Table C-5.

TABLE C-5. Percentage of Pedestrians Looking for Threats at Signalized Intersections (*41*).

Study Location	Measure of effectiveness	Baseline (Before) Conditions	After Conditions (11 or 12 months after installation)
Boland Ave. and Wyse Road, Nova Scotia	Percent of pedestrians not looking for any threat	18	3
	Percent of pedestrians looking for all threats	15	33
	Number of conflicts per 100 pedestrians	2.7	0
Main Street and Major Street, Nova Scotia	Percent of pedestrians not looking for any threat	15	5
	Percent of pedestrians looking for all threats	12	35
	Number of conflicts per 100 pedestrians	3.1	0
Ft. Harrison Ave. and Pierce St., Clearwater, Florida	Percent of pedestrians not looking for any threat	15	7
	Percent of pedestrians looking for all threats	16	31
	Number of conflicts per 100 pedestrians	2.5	0

GENERAL DESIGN

There are numerous crossing treatments that can be grouped into the general design category. Oftentimes these design elements are used in combination with one or several other primary treatments to further enhance the safety and effectiveness of pedestrian crossings. The most common examples of general design elements include:

- Median refuge with angled or staggered pedestrian opening,
- Landscaped median to discourage crossing at inappropriate location(s),
- No on-street parking in vicinity of crossing location,
- Accessible crosswalk ramps,
- Adequate street lighting,
- Shortened curb radius for shorter crossing time, and
- Curbside railing to direct pedestrians to appropriate crossing location(s).

Median Refuge Islands

Median refuge islands simplify the street crossing task by permitting pedestrians to make vehicle gap judgments for one direction of traffic at a time. Recent refuge island designs incorporate an angled or staggered pedestrian opening, which better aligns pedestrians to face the second direction of oncoming traffic.

A study by Bacquie et al. compared median refuge islands and split pedestrian crossovers in an analysis of crash reports at 10 crossing locations in Toronto, Canda (*42*). The split pedestrian crossover treatment includes a median refuge island with pedestrian-activated signal control. The crash data were not normalized by exposure data, but some indication was given about pedestrian and vehicle exposure for the two treatments. The study found that pedestrians were seldom struck while standing on the refuge island and were more often struck while crossing due to poor gap judgment or improper driver yielding. Vehicle rear-end collisions were higher at the split pedestrian crossovers, as it is a less common form of traffic control than typical intersection signals. The authors indicated some drivers did not act uniformly when approaching the split pedestrian crossovers, as the drivers may not know when to stop or if other drivers will stop in front or behind them.

ENFORCEMENT

Although not an engineering treatment, enforcement can be used in conjunction with engineering treatments to improve the safety and effectiveness of pedestrian crossings. This section documents the experience with enforcement of the following:

- Enforcement of motor vehicle yielding (“crosswalk sting”), and
- Enforcement of pedestrian crossing (jaywalk enforcement).

The Harborview Injury Prevention and Research Center and the Washington State Traffic Safety Commission collaborated on a study of the effects of increased police enforcement on motorist yielding (*43*). The State of Washington passed a law in 1990 that required motorists to stop for a pedestrian attempting to cross at a marked crosswalk (the previous law required motorists to yield). Thus, these two groups were interested in ascertaining the effects of increased enforcement on motorist yield behavior at marked crosswalks. Over a 4-year period, increased enforcement was carried out in several distinct enforcement efforts. A before-and-after study design was used to assess changes in driver yielding due to increased enforcement. Staged pedestrians were also incorporated as an element of the study design to ascertain changes in yielding behavior. The following results were reported:

- After the first enforcement campaign, driver yielding was unchanged at 19 percent of drivers yielding to pedestrians.
- The second enforcement campaign focused on specific neighborhoods and did result in modest improvements in driver yielding. The majority of drivers, however, still did not yield to pedestrians.
- The last two campaigns had mixed results that varied quite a bit by location.

The study’s conclusions indicated that the “authors have been unable to demonstrate that law enforcement efforts directed at motorist violators of crosswalk laws significantly or consistently increase drivers’ willingness to stop for pedestrians. It appears that even with a high degree of commitment on the part of law enforcement, the expectations from such programs should remain modest.”

APPENDIX D

PEDESTRIAN CROSSING TREATMENTS

SUMMARY OF ITE INFORMATIONAL REPORT

The ITE Pedestrian and Bicycle Task Force prepared an Informational Report (*44*), which documents studies on crosswalks and warrants used by various entities. The report does not discuss the merits of providing marked crosswalks on multilane higher volume roadways but summarizes various studies on pedestrian crossings. The report also assembles in a single document the various treatments currently in use by local agencies in the United States, Canada, Europe, New Zealand, and Australia to improve crossing safety for pedestrians at locations where marked crosswalks are provided for pedestrians rather than simply removing them. Section 4 on major street crossings at uncontrolled locations and Section 7 on midblock signals are summarized in this Appendix because they directly relate to the research for TCRP D-08 on Improving Pedestrian Safety at Unsignalized Roadway Crossings.

Treatments at Major Street Crossings at Uncontrolled Locations

Providing marked crosswalks using two white 1-inch (2.54 cm) lines and the warning signs prescribed by various manuals as shown in Figure D-1 were found to result in higher pedestrian collisions compared to not providing marked crosswalks on multilane roads with more than one lane in each direction with average daily volumes of 10,000 vehicles per day by the FHWA study on marked crosswalks at uncontrolled locations (31). On roads with one lane in each direction and average daily volumes of less than 10,000 vehicles per day, the FHWA study found no difference in collisions involving pedestrians at marked and unmarked crosswalks at uncontrolled intersections. To respond to this finding, some agencies removed marked crosswalks on higher volume multilane facilities. Other agencies addressed this issue by experimenting with alternative treatments to improve the safety of pedestrian crossings.

Figure D-1. Pedestrian Crossing Using Traditional Treatments.
(Source: Nazir Lalani, Ventura, California, U.S.A.)

In response to a growing need for better information on pedestrian crossing treatments to be compiled into a single comprehensive document, the ITE Pedestrian and Bicycle Task Force prepared an informational report entitled *"Alternative Treatments for At-Grade Pedestrian Crossings"* (*44*). This report summarizes information on alternative treatments at the following types of pedestrian crossings:

- Major street crossings at uncontrolled locations (ITE Section 4),
- Residential street crossings (ITE Section 5),
- Removal of crosswalks (ITE Section 6),
- Signal-controlled crossings for pedestrians (ITE Section 7),
- Signalized intersection crossings (ITE Section 8), and
- School-related crossings (ITE Section 9).

For many years, marked crosswalks were installed at unsignalized roadway crossings with the minimum amount of signing and striping (as illustrated in Figure D-1). The FHWA report entitled "*Safety Effects of Marked vs. Unmarked Crosswalks at Uncontrolled Crossing Locations* (*31*) clearly identified the safety limitations of providing such crossings on higher volume multilane facilities. Section 4 of the ITE Informational Report specifically discusses 25 treatments to enhance safety at uncontrolled pedestrian crossings, including the following:

- Automated detection,
- Antiskid surfacing,
- Curb extensions,
- Curb ramps,
- Flags,
- Flashing beacons,
- In-roadway signs,
- Lane reductions,
- Markings/legends,
- Overhead signs,
- Pedestrian railings,
- Raised markers (with LEDs),
- Refuge islands,
- Street lighting,
- Textures surfacing,
- Tactile surfaces, and
- Turn restrictions.

Section 4 of the ITE Information Report (*44*) provides a summary of treatments being used throughout North America and the rest of the world to enhance pedestrian safety at unsignalized roadway crossings. The information contained in Section 4 of the ITE Informational Report (*44*) is summarized in this section of the Appendix.

Table D-1 summarizes a variety of treatments currently used by agencies to improve safety of marked crosswalks at uncontrolled locations. Evaluation studies are cited where such information was found to be available and listed in the reference section of the Appendix.

TABLE D-1. Summary of Treatments for Major Street Crossings at Uncontrolled Locations.

Treatment Type	Picture of Treatment
Roadway Signing Description – Special signs are placed in the roadway within or near the crosswalk. • Application – Crossing on higher volume multilane roads • Cost (Including Labor) in U.S. Dollars – $200–$300 per sign • Studies of Effectiveness – Field Evaluation Report (*45*), *Pedestrian Facilities Guidebook* (*46*) • Countries Where Treatment is Used – U.S.A., France, Sweden	 **New York, U.S.A.**
High-Visibility Markings Description – This method uses ladder- or “zebra”-style crosswalk pavement markings. • Application – Crossings on higher-volume multilane roads • Cost (Including Labor) in U.S. Dollars – $500-$1,000 per crossing • Studies of Effectiveness – See section 6.2 of ITE Informational Report (*44*) • Countries Where Treatment is Used – U.S.A., Europe, Australia, New Zealand	 **Puget Sound Area, Washington, U.S.A.**
Double-Posted Pedestrian Crossing Signs Description – Standard pedestrian crossing signs are installed on both sides of the approaching roadway at an uncontrolled crosswalk in addition to the near-side pedestrian warning signs posted at and in advance of the crosswalk. • Application – Uncontrolled marked crosswalk • Cost (Including Labor) in U.S. Dollars – $200 per sign • Studies of Effectiveness – None found • Countries Where Treatment is Used – U.S.A., Canada	 **Near Downtown Los Angeles, California, U.S.A.**

TABLE D-1. Summary of Treatments for Major Street Crossings at Uncontrolled Locations (continued).

<table>
<tr><th>Treatment Type</th><th>Picture of Treatment</th></tr>
<tr><td>

Advance Placement of Limit Lines

Description – Standard white Stop or Yield limit lines are placed typically 20 ft (6 m) in advance of marked, uncontrolled crosswalks.

- Application – Crossings on higher volume multilane roads
- Cost (Including Labor) in U.S. Dollars – $300-$500 per limit line
- Studies of Effectiveness – Van Houten and others (*27*, *47*), Innovative Traffic Control Technology (*48*)
- Countries Where Treatment is Used – U.S.A., Canada

</td><td>

Canada

</td></tr>
<tr><td>

Zigzag and Other Approach Restrictions

Description – "zigzag" markings are placed in advance of marked crosswalks. The standard pattern is four sets of markings on each approach. One set comprises two strokes (zig and zag), each approximately 6.6 ft (2 m) long.

- Application – All marked crossings
- Cost (Including Labor) in U.S. Dollars – $1,000-$2,000 per crossing; four sets of markings
- Studies of Effectiveness – *The Highway Code* (*49*)
- Countries Where Treatment is Used – U.K., Eire

</td><td>

London, England, U.K.

</td></tr>
<tr><td>

Pavement Legends

Description – Word legends are placed on the pavement at each end of the crosswalk to be legible to pedestrians as they are waiting to cross.

- Application – Marked crosswalks with high turning volumes
- Cost (Including Labor) in U.S. Dollars – $500 per crosswalk
- Studies of Effectiveness – Habib (*50*)
- Countries Where Treatment is Used – U.K., U.S.A.

</td><td>

London, England, U.K.

</td></tr>
</table>

TABLE D-1. Summary of Treatments for Major Street Crossings at Uncontrolled Locations (continued).

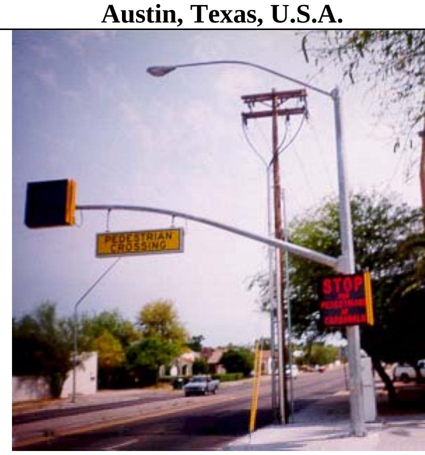
Treatment Type	Picture of Treatment
Flags Description – Pedestrians select a flag from those posted on each side of the crosswalk, flag traffic to let drivers know they wish to cross, then return the flag to the holder on the opposite side of the street after crossing. • Application – Crossings on higher volume multilane roads • Cost (Including Labor) in U.S. Dollars – $100 including holding racks per crossing • Studies of Effectiveness – None found • Countries Where Treatment is Used – U.S.A.	 **Kirkland, Washington, U.S.A.**
Fluorescent Yellow Green Signs Description – Pedestrian signs made of the FHWA-approved fluorescent yellow-green color are posted at crossings. • Application – Pedestrian and bicycle crossings including schools • Cost (Including Labor) in U.S. Dollars – $200-$300 per sign • Studies of Effectiveness – Kittle (*51*) • Countries Where Treatment is Used – U.S.A.	 **Austin, Texas, U.S.A.**
Overhead Signs Description – Warning signs are installed using span wire or mast arms. • Application – Crossings on higher volume multilane roads • Cost (Including Labor) in U.S. Dollars – $15,000-$25,000 per overhead sign • Studies of Effectiveness – None found • Countries Where Treatment is Used – U.S.A., Canada	 **Tucson, Arizona, U.S.A.**

TABLE D-1. Summary of Treatments for Major Street Crossings at Uncontrolled Locations (continued).

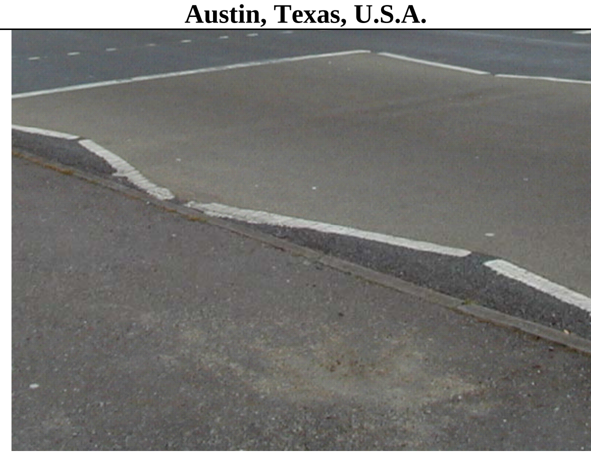
Treatment Type	Picture of Treatment
Refuge Islands Description – Raised islands with minimum dimension of 4-6 ft (1.2-1.8 m) wide and 8-12 ft (2.4-3.6 m) long are placed in the center of the roadway, separating opposing lanes of traffic and slotted along the pedestrian path. • Application – Marked and unmarked crossings • Cost (Including Labor) in U.S. Dollars – $20,000-$40,000 per island • Studies of Effectiveness – Lalani (*52*) • Countries Where Treatment is Used – U.S.A., Europe, Australia, Canada, New Zealand	 **Austin, Texas, U.S.A.**
Anti -Skid Surfacing Description – Application to pavements of a unique surface treatment improves skid resistance during wet weather. • Application – Any pedestrian crossing • Cost (Including Labor) in U.S. Dollars – $2,000-$4,000 for two approaches • Studies of Effectiveness – London Research Centre (*53*) • Countries Where Treatment is Used –Europe	 **United Kingdom**
Pedestrian Railing Description – Railings are placed along the top of the curb; typically they must be 4 ft (1.2 m) high to be effective. • Application – Any pedestrian crossing • Cost (Including Labor) in U.S. Dollars – $100 per linear meter • Studies of Effectiveness – Lalani (*54*) • Countries Where Treatment is Used – Europe, Australia	 **United Kingdom**

TABLE D-1. Summary of Treatments for Major Street Crossings at Uncontrolled Locations (continued).

Treatment Type	Picture of Treatment
In-Pavement Raised Markers Description – Both sides of a crosswalk are lined with durable encased raised pavement markers, typically containing amber LED strobe lighting activated either by push buttons or by automatic detection bollards using infrared sensors. • Application – Some agencies have guidelines, see ITE Report (*44*) • Cost (Including Labor) in U.S. Dollars – $15,000-$40,000 per crossing • Studies of Effectiveness – Huang et al. (*55*), In-Pavement (*56*), Godfrey and Mazzella (*57*) • Countries Where Treatment is Used – U.S.A.	 **Orlando, Florida, U.S.A.**
Street Lighting Description – Lights are installed, generally 150-watt bulbs at 100 ft (30 m) spacing, 10 to 11.5 ft (3 to 3.5 m) high, on both sides of the street. • Application – Crossings with high nighttime activity • Cost (Including Labor) in U.S. Dollars – $2,000-$3,000 per light • Studies of Effectiveness – Lalani (*58*) • Countries Where Treatment is Used – All Developed Countries	 **Ventura, California, U.S.A.**
Flashing Beacons Description – Flashing amber lights are installed on overhead signs, signs in advance of the crosswalk, or signs located at the entrance to the crosswalk on pedestal poles. • Application – Marked uncontrolled crossings • Cost (Including Labor) in U.S. Dollars – $10,000-$40,000 per crossing depending on placement • Studies of Effectiveness – Van Houten and Malenfant (*59*) • Countries Where Treatment is Used – U.K., U.S.A., Australia, Canada, and New Zealand	 **Austin, Texas, U.S.A.**

TABLE D-1. Summary of Treatments for Major Street Crossings at Uncontrolled Locations (continued).

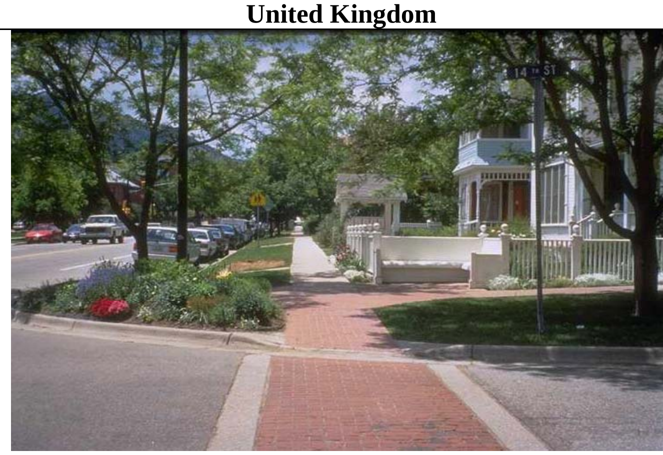
Treatment Type	Picture of Treatment
Curb Extensions The sidewalk extends across the parking lanes to the edge of the travel lanes to narrow the distance of the road that a pedestrian has to cross. • Application – Any crossing • Cost (Including Labor) in U.S. Dollars – $5,000-$25,000 depending on materials used • Studies of Effectiveness – Ewing (*60*) and *Canadian Guide* (*61*) • Countries Where Treatment is Used – U.S.A., U.K., Eire, Australia, Canada	 **Bozeman, Montana, U.S.A.**
Lane Reductions Description – The number of travel lanes are reduced by the number of travel lanes by widening the sidewalks, adding bike and parking lanes, converting parallel parking to angled or perpendicular parking, or converting one-way streets to two-way with a center median. • Application – Segments of roadway • Cost (Including Labor) in U.S. Dollars – $50,000-$5,000,000 depending on length of project • Studies of Effectiveness – None found • Countries Where Treatment is Used – U.S.A., Canada [Example shown is U.K.]	 **United Kingdom**
Textured Surfaces Description – Crosswalks are constructed with stamped concrete or asphalt, as well as brick pavers laid in a pattern. • Application – Any crossing • Cost (Including Labor) in U.S. Dollars – $10,000-$35,000 per crossing • Studies of Effectiveness – Ewing (*60*) and *Canadian Guide* (*61*) • Countries Where Treatment is Used – U.S.A., Europe, Canada	 **Boulder, Colorado, U.S.A.**

TABLE D-1. Summary of Treatments for Major Street Crossings at Uncontrolled Locations (continued).

Treatment Type	Picture of Treatment
Tactile Ground Surface Indicators Description – Various patterned, tactile ground, or floor surfaces provide directional and hazard warning information to pedestrians who are blind or visually impaired. • Application – Any crossing used by the visually impaired • Cost (Including Labor) in U.S. Dollars – $50-$200 per square meter • Studies of Effectiveness – Tactile (*62*), Guidance (*63*), Savil et al. (*64*, *65*), Japanese (*66*), Sawai et al. (*67*) • Countries Where Treatment is Used U.S.A., Europe/U.K., Australia, Canada	 **United Kingdom**
Automated Detection Description – Uncontrolled crosswalks are fitted with automated detection devices that activate flashing beacons, in-pavement raised markers with LED strobe lights, or other active warnings to alert drivers when pedestrians are present • Application – Any crossing with active devices • Cost (Including Labor) in U.S. Dollars – $500-$1,000 for microwave and infrared, $15,000-$20,000 for video cameras • Studies of Effectiveness – Huang et al. (*55*) • Countries Where Treatment is Used – U.S.A., Europe, Canada, Australia	 **Portland, Oregon, U.S.A.**
Reduced Curb Radii Description – Corner curbs have shorter radii to narrow the distance of the road that a pedestrian has to cross. • Application – Crossings with minimal truck turns • Cost (Including Labor) in U.S. Dollars – $5,000-$10,000 per corner • Studies of Effectiveness – Ewing (*60*) and *Canadian Guide* (*61*) • Countries Where Treatment is Used – U.S.A., Europe, Canada, Australia, and most developed countries	 **Ventura, California, U.S.A.**

TABLE D-1. Summary of Treatments for Major Street Crossings at Uncontrolled Locations (continued).

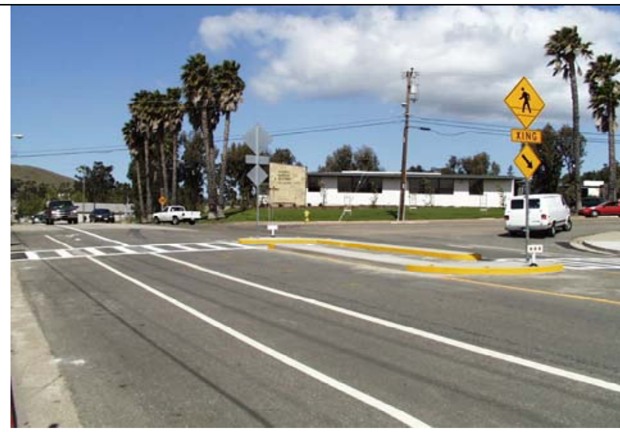
Treatment Type	Picture of Treatment
Staggered Pedestrian Refuge Islands Description – Raised islands laid out in a staggered configuration at uncontrolled intersections require pedestrians to walk toward traffic to reach the second half of the crosswalk. • Application – Across multilane roads • Cost (Including Labor) in U.S. Dollars – \$25,000-\$75,000 • Studies of Effectiveness – Bacquie et al. (*42*) • Countries Where Treatment is Used – U.S.A., Europe	 **San Luis Obispo, California, U.S.A.**
Detectable Warnings Description – A standardized surface feature composed of raised truncated domes that informs pedestrians who are visually impaired of the hazards immediately ahead. • Application – Ramps and curbs adjacent to crossings • Cost (Including Labor) in U.S. Dollars – \$200-\$2000 per ramp or curb depending on total area • Studies of Effectiveness – Bentzen and others (*68*, *69*, *71, 72*), Hauger et al. (*69*),Hughes (*70*) • Countries Where Treatment is Used – Europe, U.S.A., Australia	 **Roseville, California, U.S.A.**
Left-Turn Restrictions Description – Curbed islands that restrict left turns from side street approaches onto the street where marked crosswalks are located. • Application – Uncontrolled intersections with marked crosswalks • Cost (Including Labor) in U.S. Dollars – \$25,000-\$35,000 per crossing island • Studies of Effectiveness – None found • Countries Where Treatment is Used – U.S.A.	 **U.S.A.**

TABLE D-1. Summary of Treatments for Major Street Crossings at Uncontrolled Locations (continued).

Treatment Type	Picture of Treatment
Setback Crossings Description – Crosswalks at unsignalized intersections are set back by 9.8 ft (3 m) or more from the cross-street flow line or curb. • Application – Narrow approaches to intersections • Cost (Including Labor) in U.S. Dollars – $100 per linear meter for pedestrian railing needed for this application • Studies of Effectiveness – None found • Countries Where Treatment is Used – U.K.	 **Edinburgh, Scotland, U.K.**

Midblock Signal-Controlled Crossings for Pedestrians

Section 7 of the ITE Informational Report (*44*) summarizes the use of signals that are installed for pedestrian crossings. One of the applications is at intersections, such as in Canada, where the pedestrian crossing is signalized but the intersection side street approaches are controlled by STOP signs. Most of the applications in the U.S.A., Canada, Australia, and the U.K. are at midblock locations. These treatments have been placed in a separate section because they are not at signalized intersections and their operations are significantly different from pedestrian crossings at signalized intersections. The section discusses the following types of crossings:

- Intersection pedestrian signals,
- HAWKs,
- Midblock signals,
- Pedestrian intersection crossings,
- Pelican,
- Puffins, and
- Toucans.

Table D-2 summarizes the information contained in Section 7 of the ITE Informational Report (*44*).

TABLE D-2. Summary of Midblock Signal-Controlled Crossings for Pedestrians.

Treatment Type	Picture of Treatment
Midblock Signal-Controlled Pedestrian Crossings with Flashing Red Description – At a signal-controlled midblock crosswalk, drivers either stop for 12 to 20 seconds during the steady red signal indication displayed during the WALK interval or pause for 4 to 7 seconds during a flashing red indication that signals the DON'T WALK interval. • Application – Midblock locations in high pedestrian activity areas such as downtowns • Cost (Including Labor) in U.S. Dollars – $50,000-$100,000 per installation • Studies of Effectiveness – None found • Countries Where Treatment is Used – U.S.A.	 **Los Angeles, California, U.S.A.**
Midblock Signal-Controlled Pedestrian Crossings Description – At a signal-controlled midblock crosswalk, drivers stop at the steady red indication – activated by push button – displayed on either WALK or DON'T WALK intervals, and may only proceed once the signal turns green. • Application – Midblock locations in high pedestrian activity areas such as downtowns • Cost (Including Labor) in U.S. Dollars – $50,000-$100,000 per installation • Studies of Effectiveness – Glock et al. (*4*) • Countries Where Treatment is Used – Canada, U.S.A.	 **Tucson, Arizona, U.S.A.**
Intersection Pedestrian Signals (Half-Signals) Description – Signals installed at intersections control traffic at crosswalks on the major streets. The side street is controlled by STOP signs, while no signal indications are provided for the minor street traffic. • Application – Signalized pedestrian crossings with the side street STOP signs • Cost (Including Labor) in U.S. Dollars – $50,000-$100,000 per installation • Studies of Effectiveness – Unpublished study by City of Portland, Oregon • Countries Where Treatment is Used – Canada, U.S.A.	 **Portland, Oregon, U.S.A.**

TABLE D-2. Summary of Midblock Signal-Controlled Crossings for Pedestrians (continued).

Treatment Type	Picture of Treatment
Pelican Crossings Description – **Pe**destrian **li**ght **con**trolled crossings (Pelican) control vehicular traffic at midblock crosswalks with either a steady red signal (stop), flashing amber indication (proceed if no pedestrians), or steady green signal (proceed). • Application – Midblock locations in high pedestrian activity areas • Cost (Including Labor) in U.S. Dollars – \$50,000-\$100,000 • Studies of Effectiveness – Lalani (*54*) and Traffic Advisory Unit (*71*) • Countries Where Treatment is Used – U.K., Australia, U.S.A., Eire	 **Victoria, Australia**
Puffin Crossings Description – **P**edestrian **u**ser **f**riendly **in**telligent (Puffin) crossings are similarly constructed as Pelicans, but provide more flexibility in crossing time for pedestrians, use nearside pedestrian signal heads as opposed to farside, and provide an extendable all-red crossing period using microwave, infrared, and other types of overhead detection. • Application – Midblock locations in high pedestrian activity areas • Cost (Including Labor) in U.S. Dollars – \$50,000-\$100,000 • Studies of Effectiveness – Lalani (*54*) and Department of Transportation (*72*) • Countries Where Treatment is Used – U.K., Australia, U.S.A., Eire	 **Victoria, Australia**

TABLE D-2. Summary of Midblock Signal-Controlled Crossings for Pedestrians (continued).

Treatment Type	Picture of Treatment
Toucan Crossings Description – Toucan crossings (two can cross) are similar in vehicular detection to the Pelican and Puffin crossings and in pedestrian on-crossing detector to the Puffin crossing, but differ in providing bicycle signals for bicyclists and displaying dark pedestrian/bicycle signals instead of the flashing green walking figure. • Application – Midblock locations in high pedestrian and bicycle activity areas • Cost (Including Labor) in U.S. Dollars – $75,000-$100,000 • Studies of Effectiveness – London (*73*,*74*) • Countries Where Treatment is Used – U.K., U.S.A.	 **Tucson, Arizona, U.S.A.**
HAWK Crossings Description – The **H**igh-intensity **a**ctivated cross**w**al**k** (HAWK) signaling system in Tucson, Arizona, is a combination of a beacon flasher and a traffic control signaling technique for marked crossings that remains off unless activated by a pedestrian. • Application – In high pedestrian areas • Cost (Including Labor) in U.S. Dollars – $40,000-$60,000 • Studies of Effectiveness – Glock (*4*) • Countries Where Treatment is Used – Canada, U.S.A.	 **Tucson, Arizona, U.S.A.**

NEW CROSSING TREATMENTS

Staggered Crosswalks with Speed Monitoring Signs in Phoenix, Arizona

The city of Phoenix, Arizona, installed an offset crosswalk in mid-August 2002 prior to the beginning of the school year. The location is at an intersection directly in front of a large high school in North-Central Phoenix. Previously, two marked crosswalks served the school, but one was at a location of concern (directly behind an area where the roadway was raised for a canal). This vertical curve made the crosswalk less visible to traffic approaching from the west. Additionally, the other, primary, crosswalk crossed two westbound lanes, a two-way left-turn lane, and three eastbound lanes. During the morning student drop-off hours, safety concerns centered on vehicular traffic backing up in the two-way left-turn lane through the crosswalk, waiting to turn left into the school parking lot. The parent-teacher group at the high school was well organized and vocal, and they successfully publicized their concerns by holding a large public forum requesting that the city "solve" this problem by installing a signal.

The crosswalk location was awkward for signalization, as spacing was poor and a signal could not be made to fit within the current synchronized signal system. Phoenix staff worked with the parent-teacher group, students, and school officials to find ways of improving safety at the primary crosswalk and eliminating the secondary crossing location, prohibiting students from crossing at that location. The primary crosswalk was already eligible for enhancement under a citywide School Safety Improvement Program by which school-related crosswalks would have oversized fluorescent yellow-green crossing signs installed and the word SCHOOL stenciled in each lane. After analyses, Phoenix staff suggested adding a European flavor (staggering the crosswalk), along with further testing of experimental speed monitors that looked promising for use based on experimentation at two other locations in Phoenix.

Staggering crosswalks is a practice used selectively in Great Britain. The practice recognizes the simple fact as streets get wider, they become more difficult to successfully navigate across the street. Crossing requires sizable gaps in the traffic stream, which do not appear as frequently as desired, and impatient pedestrians may be tempted to take chances. Additionally, on two-way streets, pedestrians are required to look both ways to assure safe separation exists. Using an offset crosswalk improves both of those situations.

For the staggered crosswalk to work effectively, it is essential to have a safe refuge in the center of the street. To accomplish this, Phoenix built a raised island in the middle of what used to be a two-way left-turn lane. To work most effectively, the offset also needs to be designed to direct pedestrians toward the traffic stream they are about to cross. To curtail short-cutting and to force pedestrians to follow the intended path, the city outlined the raised median island with attractive fencing to "corral" the students. Students approach the crosswalk facing traffic going in the direction that they must cross. They cross to the refuge island, where the fencing requires them to turn at a right angle and pause, separately crossing the second half of the street. Again, as they enter that traffic stream they are facing the traffic in which they want to pick a gap. To provide comfortable room for pedestrians and have room for ramp slopes (and to reserve room for fencing), it is desirable that the raised median island be a minimum of 8 ft wide. In this case, the island was built 9 ft (2.7 m) wide, which required narrowing the through lanes past the raised island. This has been found to inhibit speeding, in a gentler manner than chicanes accomplish on local residential streets.

Additionally, Phoenix added some innovation by installing some experimental speed monitor signs on the approaches to the school. These speed monitors work in the same manner as speed trailers, since they have built-in radars that measure speeds of approaching drivers and depict them on a changeable message sign. Phoenix bought some additional features in the speed monitors: at this offset crosswalk location there is a feature whereby above a certain speed threshold, a white beacon goes off (much the same as with photo enforcement flashes). While drivers are not given citations, the feature is effective in reducing speeds. At other locations where speed monitors are used, they are designed to activate a changeable sign so above certain threshold speeds, the monitors indicate SLOW NOW.

Figure D-2 shows pictures of the staggered crosswalk installation in Phoenix. Although this crossing is near a school, this type of design can be used at any crossing location.

Figure D-2. Staggered Crosswalk in Phoenix, Arizona.
(Source: James Sparks, Phoenix, Arizona, U.S.A.)

Figure D-3 shows a similar installation in the Las Vegas area of Nevada. This location does not include the pedestrian railing on the island, which is a prominent feature of the British design.

Figure D-3. Staggered Crosswalk in the Las Vegas Area of Nevada.
(Source: Rich Romer, Las Vegas, Nevada, U.S.A.)

Pedestrian-Activated Beacons and Lights in Salt Lake City, Utah

In March 2001, Salt Lake City's first pedestrian-actuated overhead flashing beacons were installed over a busy four-lane street at a high pedestrian volume crosswalk. This device consists of one beacon over each travel lane on the approach to the crossing and two pedestrian crosswalk signs mounted back to back hung overhead (see Figure D-4). The beacons flash in an alternating pattern once the pedestrian pushes the activation button for a period equivalent to the pedestrian clearance interval plus 10 seconds.

A second pedestrian-activated flashing beacon-type crosswalk has been installed and an existing constantly flashing installation has been converted to pedestrian-actuated activation. These installations cost $9000, compared to $25,000 for in-pavement flashing marker-type installations when used with existing utility poles with overhead power in close proximity.

Figure D-4. Pedestrian-Activated Flashing Beacons in Salt Lake City, Utah.
(Source: Tim Harpst, Salt Lake City, Utah, U.S.A.)

A further enhancement of this system is the addition of crosswalk nighttime illumination activated by a pedestrian pushbutton (see Figure D-5). During nighttime hours, street lighting attached to the crosswalk mast arm configured to illuminate the crosswalk area is lit at 30 percent capacity. When the pedestrian pushbutton is activated, the light illuminates the crosswalk at full capacity during the time that the overhead flashers are activated. Salt Lake City uses this only where there are high pedestrian flows during evening hours. These installations were reported in the November –December 2002 ITE District 6 newsletter, the *Westernite* (*75*).

Figure D-5. Pedestrian-Activated Beacons with Light Illumination in Salt Lake City, Utah. (Source: Tim Harpst, Salt Lake City, Utah, U.S.A.)

Triple-Four High-Visibility Markings in Sacramento, California

Triple-four high-visibility markings are used in Sacramento, California, to make unsignalized pedestrian crossings more visible to drivers. This treatment is a variation of the ladder or zebra style of high-visibility markings. The city's *Pedestrian Safety Guidelines* (*76*) indicate that this treatment should be used where:

- Sufficient demand exists to justify the justify the installation of a crosswalk;
- The location is 300 ft (91.4 m) or more from a controlled crossing location;
- The location has sufficient sight distance, or sight distance will be improved prior to crosswalk marking; and
- Safety considerations do not preclude a crosswalk.

Figure D-6 shows an example of such an installation.

Figure D-6. Triple-Four High-Visibility Markings in Sacramento, California.
(Source: Nazir Lalani, Ventura County, California, U.S.A.)

Five-Bar Triangle Advance Crosswalk Pavement Markings in Salt Lake City, Utah

Salt Lake City staff designed a five-bar triangle advance crosswalk pattern for use at midblock crosswalks on higher speed streets (see Figure D-7). The pattern consists of five rectangular white pavement markings, sized and placed to form triangles on travel lanes in advance of midblock crossings. The markings alert the presence of pedestrians at unsignalized crossings on high-volumes streets. The pattern has been installed at four locations at a cost of $75 per triangle per lane.

Figure D-7. Five-Bar Triangle Advance Crosswalk Pavement Markings in Salt Lake City, Utah.
(Source: Tim Harpst, Salt Lake City, Utah, U.S.A.)

In-Roadway Signs at Michigan State University, East Lansing, Michigan

In response to a series of pedestrian-related collisions at unsignalized pedestrian crossings, Michigan State University re-engineered midblock pedestrian crossings by installing high-visibility markings and yellow triangular “Yield to Pedestrians” signs. These signs were positioned on the leading edge of the high-visibility markings (see Figure D-8). The university staff reported (*77*) very positive results from this treatment.

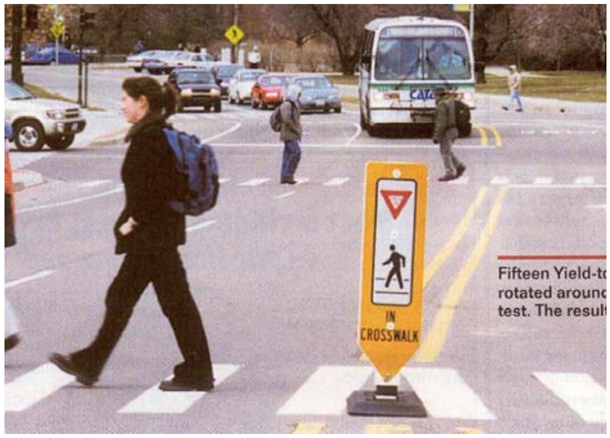


Figure D-8. In-Roadway Sign Type in East Lansing, Michigan (77).

Crosshatched Crosswalk Markings in Arcadia, California

Diagonal markings highlight a pedestrian crossing area adjacent to a post office where 4000 pedestrians per day cross after parking across the street (see Figure D-9). The marked section is 110 ft (33.5 m) long and 28 ft (8.5 m) wide. The pavement was raised by 2 inches (5.1 cm) to create an elevated section. The area is bounded by patterned pavement surfacing at each end of the diagonally marked area to ramp traffic up to the elevated section. The patterned paving creates an audible rumble when vehicles travel over it, thereby giving notice to pedestrians that traffic is approaching.

Figure D-9. Crosshatched Crosswalk Markings in Arcadia, California.
(Source: Ed Cline, Arcadia, California, U.S.A.)

Overhead Animated Eye Display at Midblock Crossings

Animated eye display uses an LED pedestrian signal head and adds animated eyes that scan from side to side at signalized intersections (see Figure D-10). The device uses narrow (8 degree) field of view LEDs on a black background. At signalized intersections, the display is highly visible to pedestrians while limiting pedestrian signal displays to drivers. The blue LEDs present to the pedestrian a display consisting of two blue eyes with blue eyeballs that appear to scan from left to right at the rate of one cycle per second. Animated eyes displays are designed to encourage pedestrians to look for turning vehicles traveling on an intersecting path by including a prompt as part of the pedestrian signal display.

In this adaptation in the Puget Sound area of Washington, the animated eyes are displayed to drivers approaching midblock crosswalks to encourage them to look for pedestrians. A beacon also flashes when the pedestrian activates the animated eye display.

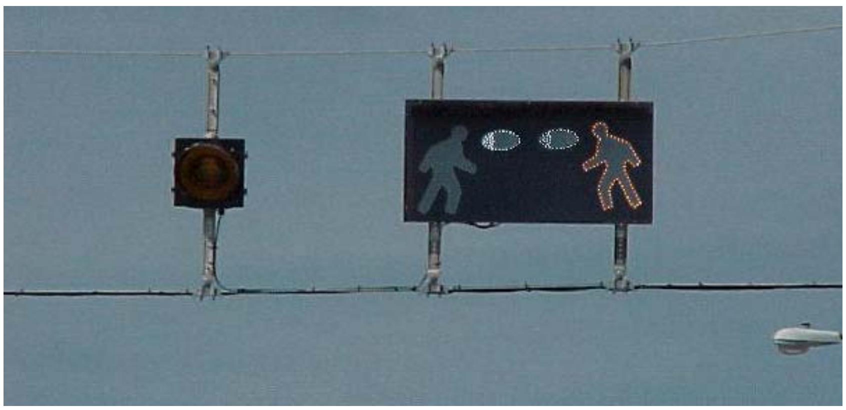


Figure D-10. Overhead Animated Eye Display in the Puget Sound Area, Washington. (Source: Julie Mercer-Matlick, Olympia, Washington, U.S.A.)

Midblock Crosswalk with Overhead Signs and Pedestrian Refuge Island

The treatment shown in Figure D-11 shows a midblock unsignalized pedestrian crossing with overhead signs, high-visibility markings, and a pedestrian refuge island.

Figure D-11. Midblock Crosswalk with Overhead Signs and Pedestrian Refuge Island. (Source: Susie Stephens "Crossing the Street" Presentation at the Probike Prowalk Conference, Minneapolis, St. Paul, Minnesota, U.S.A.)

Figure D-12 shows a similar installation on a multilane arterial street which includes curb extensions in the parking lanes to narrow the crosswalk.

Figure D-12. Midblock Crosswalk with Overhead Signs, Pedestrian Refuge Island, and Curb Extensions.
(Source: Susie Stephens "Crossing the Street" Presentation at the Probike Prowalk Conference, Minneapolis, St. Paul, Minnesota, U.S.A.)

Midblock Crosswalk with High-Visibility Markings, Pedestrian Refuge Island, and In-Pavement Flashing Markers

The treatment shown in Figure D-13 at a midblock crossing includes high-visibility markings, a pedestrian refuge, and in-pavement flashing lights.

Figure D-13. Midblock Crosswalk with Median Refuge Island and In-Pavement Flashing Markers.
(Source: Susie Stephens "Crossing the Street" Presentation at the Probike Prowalk Conference, Minneapolis, St. Paul, Minnesota, U.S.A.)

Crosswalk with Double-Piano Type Markings

The double–piano (DP) style markings eliminate marking material from the middle 1/3 of a ladder crosswalk marking (see Figure D-14). The marked portion of the DP crosswalk provides between 5 ft (1.5 m) and 9 ft (2.7 m) of additional sight distance and stopping clearance between pedestrians in the clear zone and approaching motorists. The unmarked "clear zone" reduces the risk of pedestrian slips and falls in wet weather. Separation in longitudinal lines has not been shown to reduce motorist visibility.

The DP pattern modifies the ladder design by striping the pattern to avoid wheel track tire wear. The modified striping pattern reduces vehicular skidding and sliding and reduces marking material replacement cost by up to five times less than other markings. It also retains markings in same ratio (1/3 marked, 2/3 unmarked) that has been found to be most visible to motorists from prior FHWA research. The DP pattern minimizes the potential for pedestrian slips, vehicular skids, replacement costs, and sight distance conflicts and better channels high peak hour pedestrian crossing volumes. As with any crosswalks, DP markings are best used in combination with stop lines and signing for unsignalized/uncontrolled midblock crossings.

The New York Department of Transportation is creating a proposal that will be submitted to the Federal Highway Administration, as required per Section 1A.10 of the *MUTCD*, to obtain permission to install and evaluate a DP marking design for midblock pedestrian and shared use path crossings.

Figure D-14. Crosswalk with Double Piano Style Markings in New York State.
(Source: James Ercolano, Albany, New York, U.S.A.)

In-Roadway Signs at Crosswalks in New York State

In combination with a change in law (*78*) to strengthen the requirement for drivers to yield to pedestrians, the State of New York DOT is deploying an in-roadway sign located in the crosswalk to reduce pedestrian-related collisions. Two types of signs used by NYDOT are shown in Figure D-15.

Figure D-15. In-Roadway Signs at Crosswalks in New York State.
(Source: James Ercolano, Albany, New York, U.S.A.)

TREATMENTS USED IN EUROPE

FHWA and AASHTO sponsored a European scanning tour focused on innovative safety practices in the planning, design, operation, and maintenance of signalized intersections or junctions. The scanning tour took place from May 10 through 26, 2002. The scanning team visited Sweden, Germany, the Netherlands, and the United Kingdom. This section of the report presents midblock pedestrian crossing treatments observed during the scan. A summary report was prepared and published by FHWA in July 2002 (*79*).

Midblock Crossing in Frankfurt, Germany

Unsignalized midblock crossings are frequently installed in the urbanized areas of Germany where there are large numbers of pedestrians needing to cross the street, especially near transit stops. Many cities have tram lines with station platforms located in the center of major streets at midblock locations. Figure D-16 shows a midblock unsignalized pedestrian crossing with four ground-mounted and overhead standard blue and white Europe pedestrian crossing signs facing each direction of approach traffic, pedestrian-activated flashing beacons, pedestrian refuge island, and high-visibility markings. Transit stops are located on each side of the crossing.

Figure D-16. Midblock Crossing in Frankfurt, Germany.

Painted Midblock Crossing in Stockholm, Sweden

Midblock crosswalks at unsignalized locations are painted on the pavement in such a way as to create an optical illusion that there is a raised crosswalk. Multiple colors create the optical illusion. No documentation was provided as to how often the crosswalk has to be repainted or whether there are any pedestrian safety benefits. Figure D-17 shows a typical location in Stockholm.

Figure D-17. Painted Raised Crosswalk in Stockholm, Sweden.

Midblock Crossing near Copenhagen, Denmark

Midblock crossings in Copenhagen are provided with high-visibility ladder-type markings, curb extensions (sometimes only on one side), and the standard European blue and white pedestrian crossings mounted overhead with flashing yellow beacons that are activated by pedestrians. Low-pressure sodium lighting is present along one side of the street. Figures D-18 and D-19 show typical midblock crossings incorporating these treatments. The second location also includes a raised crosswalk.

Figure D-18. Midblock Crossing in Copenhagen, Denmark.
(Source: Karen Whitehouse, Ventura, California, U.S.A.)

Figure D-19. Midblock Crossing with Raised Crosswalk in Copenhagen, Denmark.
(Source: Karen Whitehouse, Ventura, California, U.S.A.)

Midblock Crossing with Refuge Island in the U.K

In Figure D-20, the marked midblock crossing with refuge island is provided with internally illuminated bollards to provide nighttime illumination. Standard blue and white signing is present to illustrate to drivers the correct side of the island. Figure D-21 shows the center median striped with diagonal markings and the pavement is colored with a red pigmentation to highlight the median and the center refuge island area.

Figure D-20. Midblock Crossing with Refuge Island in the U.K.
(Source: Nazir Lalani, Ventura County, California, U.S.A.)

Figure D-21. Midblock Crossing with Refuge Island and Color-Treated Median in the U.K.
(Source: Nazir Lalani, Ventura County, California, U.S.A.)

Midblock Crossing with Refuge Island in the Netherlands

Figure D-22 shows a midblock crossing that incorporates a raised crosswalk with the standard blue and white European pedestrian crossing signs mounted overhead, high-visibility markings, a pedestrian refuge with internally illuminated bollards, and Keep Right signs. This crossing serves high pedestrian and bicycle traffic during commute times and weekends and is part of a bike path system.

Figure D-22. Midblock Crossing with Refuge Island in the Netherlands.

COMMENTS ON UNCONTROLLED CROSSINGS AND MIDBLOCK SIGNAL TREATMENTS

The initial section of this Appendix summarizes treatments identified in the ITE Informational Report (*44*) on major street uncontrolled crossings and midblock signals used mainly in Europe and Australia. The next sections identify additional treatments used at unsignalized crossings that have been recently implemented since the ITE Informational Report was prepared and summarize treatments that were documented during a scanning tour of Europe sponsored by FHWA/AASHTO in May 2002. A review of the treatments in this appendix indicates that the following treatments are well used or gaining in popularity.

In-Roadway Signs

A variety of in-roadway sign treatments have been used by a variety of agencies. Results from their use seem to indicate an improvement in driver awareness of pedestrians using crosswalks. This treatment may be especially useful on major streets with one travel lane in each direction.

In-Pavement Flashing Markers

In-pavement flashing markers are being used by public agencies in the western United States, especially in those states where snow removal is not an issue. Treatments that include pedestrian crossing signs with flashing LEDs and also flashing beacons ahead of the crosswalk seem to be the most effective.

Pedestrian Refuge Islands

Pedestrian refuge islands have been extensively used in a variety of locations to improve pedestrian safety and mobility. The crossings where such islands are used also incorporate high-visibility markings, overhead and ground-mounted signing, advance signing, and overhead flashing beacons. Canada has its own version of this type of crossing called a split pedestrian crossover. A number of agencies have recently installed staggered pedestrian refuge islands that require pedestrians to walk toward approaching traffic while on the refuge island. These locations should be studied to determine their effectiveness.

Smart Crosswalks with Activated Flashing Beacons/Overhead Sign Legends

Midblock pedestrian crossings have been implemented by several agencies in the western states of the United States where overhead flashing beacons are installed on mast arms or span wires suspended over the crossing. The beacons are activated by passive detectors when pedestrians enter the detection zone in the vicinity of the wheelchair ramp. Most of these locations also include high-visibility markings and advance signing to supplement the overhead signs and beacons. Some agencies such as Tucson, Arizona, use crossings with overhead activated flashing signs displaying a message to drivers indicating that they should stop for crossing pedestrians. These types of treatments may have wider applicability depending on their effectiveness.

Midblock Signals

The initial section of this Appendix summarizes the information contained in the ITE Informational Report on the following types of midblock signals:

- Midblock signals with flashing red,
- Midblock signals,
- Intersection pedestrian signals,
- Pelican,
- Puffins,
- Toucans, and
- HAWKs.

Pelican Crossings and Midblock Signals with Flashing Red

The city of Los Angeles, California, uses midblock signals with a flashing red indication that is displayed to drivers during the pedestrian clearance interval so that they can proceed if there are no pedestrians in front of them. This type of midblock signal is similar to the Pelican crossing used in the U.K. and Australia, except that the Pelican displays a flashing amber indication to the driver.

Midblock Signals

Midblock pedestrian signals have been in limited use for many years and are most often found in downtown areas of large cities where volumes are sufficiently high to meet the *MUTCD* pedestrian warrant. Depending on their location, they can have a disruptive effect on platoons of traffic traveling in coordinated signal systems. The city of Tucson, Arizona, developed a split midblock crossing incorporating a staggered pedestrian refuge island that requires pedestrians to cross the street using two separately operated pedestrian signals. Each signal is then coordinated with the nearest upstream signal to minimize disruption of platoons of traffic traveling in a coordinated signal system. This type of operation may have the potential for wider application, especially on larger multilane streets with center raised medians.

Intersection Pedestrian Signals (Also Called Half-Signals)

Intersection pedestrian signals are installed at intersections to control traffic for crosswalks across major streets and are extensively used in some provinces in Canada as well as the states of Oregon and Washington. The side street is controlled by STOP signs with no signal indications provided for the minor street approach traffic. These are sometimes referred to as half-signals. Recent concerns have been expressed by engineers in Canada as to the relative safety of these signals. These concerns should be investigated if these types of signals are recommended for wider use at non-midblock locations.

Puffins and Toucans

The Pelican crossing has been superseded in the U.K. by the Puffin crossing, which uses microwave detectors to change the pedestrian crossing timing based on the presence of pedestrians in the crossing. The Puffin could be adapted for use in the United States for use at midblock locations with high pedestrian volumes such as heavily used transit stops. A variation on the Puffin is the Toucan, which has separate indications and signal timing for pedestrians and bicyclists. This type of crossing is already in use in Tucson, Arizona, and could also be adapted for use in other parts of the United States.

HAWKS

The HAWK crossing display shows dark signal indications to drivers until it is activated by a pedestrian pushing a button. The signal then displays a yellow indication and then a solid red. During the pedestrian clearance interval, the driver sees a wig-wag pattern until the pedestrian clearance interval has ended, when the vehicle indication returns to dark mode. This treatment is extensively used in Tucson, Arizona, but there is ongoing concern with this type of treatment because the vehicle code in most states indicates that drivers should stop at dark signals and treat them as stop signs. The vehicle code would have to be modified to permit signals operating in dark mode at midblock locations without requiring drivers to stop.

CONCLUSIONS

Based on the information reviewed and obtained from many different sources during the preparation of this Appendix, the following conclusions were drawn concerning pedestrian safety at unsignalized roadway crossings:

- Since the publication of the ITE Informational Report (*44*), a number of agencies have implemented alternative treatments for midblock unsignalized pedestrian crossings. These recently implemented treatments could be studied to determine their effectiveness.
- Midblock signalized crossings with operational characteristics that minimize delay to vehicular traffic have been implemented successfully in North America, Europe, and Australia. Warrants could be developed to permit the use of these types of crossings at midblock locations where there is pedestrian demand generated by transit facilities.
- Treatments used at midblock unsignalized locations in Europe could be tested in locations in the United States to determine if they are effective.

APPENDIX E

SUMMARY OF PEDESTRIAN CROSSING TREATMENT EVALUATIONS

This Appendix summarizes the major evaluation findings for various pedestrian crossing treatments at uncontrolled locations. The findings are summarized in Table E-1, which gathers information from the full literature review contained in Appendix D.

TABLE E-1. Summary of Pedestrian Crossing Treatment Evaluations.

Crossing Treatment(s) and Study Site Location	Reported Effectiveness	Experimental Design [Reference or Study]	Discussion
Traffic Signal and Red Beacons			
Signal that rests in steady green, goes to red ball when activated with STOP sign on minor street (half-signal) (18 locations in Seattle, Washington)	After installation of half-signals, vehicular crashes remained constant (19 before, 19 after), whereas vehicle-pedestrian crashes declined from 4 to 0.	Retrospective before-and-after vehicle and pedestrian crash analysis (equal time periods ranging from 7 to 30 months) [Fairfax 1974 (*80*), as reported in Fairfax 1999 (*81*)]	Study indicates overall 17 percent reduction in total crashes (vehicle-vehicle and vehicle-pedestrian). Author concludes that pedestrian safety has been significantly improved.
Flashing yellow signal with flashing red beacon on minor street (1 location each in Memphis, Tennessee, and Sioux City, Iowa)	The study compared this treatment to full signalization using numerous MOEs such as vehicle and pedestrian behavior, vehicle and pedestrian compliance, and driver understanding. The authors concluded that this treatment "is equivalent to full signalization, except that full signalization may generate through traffic on minor street approach."	Matched experimental and control sites with time series evaluation [Petzold and Nawrocki (*82*)]	Four treatments were tested for their effectiveness at school-pedestrian crossings. This design was not considered the most desirable crossing treatment tested.
Flashing green signal with STOP sign on minor street (1 location each in Lincoln, Nebraska, and Seattle, Washington)	The study compared this treatment to full signalization using numerous MOEs such as vehicle and pedestrian behavior, vehicle and pedestrian compliance, and driver understanding. The authors concluded that this treatment "…is more desirable to full signalization."	Matched experimental and control sites with time series evaluation. For this experiment only, the existing steady green signals were changed to flashing green signals. [Petzold and Nawrocki (*82*)]	Four treatments were tested for their effectiveness at school-pedestrian crossings. This design was not considered the most desirable crossing treatment tested. The Lincoln and Seattle signals had been in operation for 11 and 5 years, respectively.

TABLE E-1. Summary of Pedestrian Crossing Treatment Evaluations (continued).

Crossing Treatment(s) and Study Site Location	Reported Effectiveness	Experimental Design [Reference or Study]	Discussion
Steady green signal with STOP sign on minor street (1 location each in Lincoln, Nebraska, and Seattle, Washington)	The study compared this treatment to full signalization using numerous MOEs such as vehicle and pedestrian behavior, vehicle and pedestrian compliance, and driver understanding. The authors concluded that this treatment "…is more desirable to full signalization."	Matched experimental and control sites with time series evaluation [Petzold and Nawrocki (*82*)]	Four treatments were tested for their effectiveness at school-pedestrian crossings. Along with crossing guards, this design was considered the most desirable school-pedestrian crossing treatment tested. The Lincoln and Seattle signals had been in operation for 11 and 5 years, respectively.
Steady green signal with STOP sign on minor street (half-signal) (22 locations in Seattle, Washington)	After installation of half-signals, the vehicle-pedestrian crash rate (per million vehicles entering intersection) dropped 65 percent (49 before, 18 after) and the vehicle-vehicle crash rate declined by 10 percent (470 before, 425 after).	Retrospective before-and-after vehicle and pedestrian crash analysis (average of 14.5 years of crash data) [Hendrickson (*83*), as reported in Fairfax 1999 (*81*)]	Rear-end vehicle crashes were significantly reduced after installation of half-signals. The author suggested that the half-signals "corrected the situation where a driver stopped abruptly for a crossing pedestrian…"
Steady green signal with STOP sign on minor street (half-signal) (18 locations in Seattle, Washington, same as those evaluated in Fairfax 1974)	Crash history of 25 years of half-signal operation yields the following: (a) Major street vehicle-minor street vehicle, 0.33 crashes per year per location; (b) Major street vehicle-pedestrian in signalized crosswalk, 0.02 crashes per year per location; (c) Major street vehicle-pedestrian in closed crosswalk, 0.009 crashes per year per location; (d) Minor street vehicle-pedestrian in signalized crosswalk, 0.009 crashes per year per location; (e) Minor street vehicle-pedestrian in closed crosswalk, 0 crashes per year per location.	Retrospective "after" vehicle and pedestrian crash analysis (25 years of "after" crash data) [Fairfax 1999 (*81*)]	Author suggests that 25-year crash history demonstrates that half-signal "…highly effective in providing pedestrian and vehicular safety."
Half-signal, advance stop lines, and motorist prompting signs (1 location in St. Petersburg, Florida)	After installation of the half-signal and other treatments, motorists yielding to pedestrians increased from 3 to 100 percent. Vehicle-pedestrian conflicts decreased from 4 to 0 percent.	Before-and-after motorist compliance and vehicle-pedestrian conflicts study [CUTR 2000 (*14*)]	Multiple crossing treatments were used at this location. The improvements in the MOEs were the most dramatic found in the study.

TABLE E-1. Summary of Pedestrian Crossing Treatment Evaluations (continued).

Crossing Treatment(s) and Study Site Location	Reported Effectiveness	Experimental Design [Reference or Study]	Discussion
HAWK signal or modified half-signal (1 location in Tucson, Arizona)	After HAWK signal installation, drivers yielding to pedestrians increased from 31 to 93 percent. Pedestrians who ran, hesitated, or aborted their crossing decreased from 24 to 10 percent.	Before-and-after motorist compliance and pedestrian behavior study [Glock, Nassi, Hunt, and Fairfax 2000 (*4*); Nassi 2001 (*3*)]	Since its introduction, the appearance of the HAWK signal has evolved from a traditional traffic signal to that of an emergency vehicle beacon.
Flashing green signal with STOP sign on minor street (half-signal) (12 locations in Greater Vancouver area, British Columbia [Canada])	STOP sign compliance rate on side streets ranged from 36 to 100 percent, with 10 of the 12 locations having compliance rates less than 90 percent.	Traffic control device compliance [Voss and Parks 2001 (*2*)]	Design and operational inconsistency among half-signal installations may be contributing to poor STOP sign compliance.
Pedestrian countdown signal (4 treatment and 2 control intersections in San Jose, California)	The proportions of pedestrians exiting on DON'T WALK decreased from 4.4 to 2.2 percent (depending upon the location). This was assumed to be due to pedestrians using the information on the timer to adjust their speed so that they finished their crossing before the DON'T WALK phase began.	Matched experimental and control sites with time series evaluation, review of crash data [Botha et al. (*13*) May 2002]	Only had 7 months of after crash data (which found that none of the crashes could be attributed to the countdown signal). Suggested educating the public about the meaning of the countdown displays and consideration of also providing a countdown in green for the WALK interval.
Pedestrian countdown signal (2 treatment and 3 control intersections in Lake Buena Vista, Florida)	The countdown signals had the positive effect of reducing the number of pedestrians who started running when the flashing DON'T WALK signal appeared. They had the undesired effect of increasing the number of pedestrians entering on the flashing DON'T WALK phase.	Matched experimental and control sites with time series evaluation [Huang and Zegeer, 2000 (*12*)]	Study recommended that the countdown signals be tested at other locations and that their use should be accompanied by public educational campaigns.
Pedestrian countdown signal (minor leg of 1 intersection, Hampton, Virginia)	Pedestrians felt the new pedestrian signals are clearer than conventional displays (88 percent) and are an improvement (82 percent).	Survey [Allsbrook (*9*) 1999]	Requested that the device remains and to install additional countdown devices on major leg of intersection.
Pedestrian countdown indication (5 sites within St. Paul and Minneapolis, Minnesota)	Pedestrians who completed the crossing before the DON'T WALK phase increased from 67 to 75 percent. About 78 percent found the new pedestrian indications easier to understand than the former indications.	Observational data (percent stepping off of curb) and intercept interviews [Farraher (*11*) 2000]	Based on the positive findings and public input, the Minnesota DOT is moving forward with identifying criteria.

TABLE E-1. Summary of Pedestrian Crossing Treatment Evaluations (continued).

Crossing Treatment(s) and Study Site Location	Reported Effectiveness	Experimental Design [Reference or Study]	Discussion
Flashing red beacon with STOP sign on minor street (1 location each in Atlanta, Georgia, and Buffalo, New York)	The study compared this treatment to full signalization using numerous MOEs such as vehicle and pedestrian behavior, vehicle and pedestrian compliance, and driver understanding. The authors concluded that full signalization "… is more desirable than the sign and STOP sign design."	Matched experimental and control sites with time series evaluation [Petzold and Nawrocki 1977 (*82*)]	Four treatments were tested for their effectiveness at school-pedestrian crossings. This design was considered the least desirable crossing treatment tested.
Flashing Beacons			
Overhead and advance flashing amber beacons (4 locations in Phoenix, Arizona)	The flashing beacons did not decrease speeds or crashes, and in some cases traffic speeds or crashes increased after installation. The authors concluded "that flashers offer no benefit for intermittent pedestrian crossings in an urban environment. In addition, the longer the flashers operate the more it becomes part of the scenery and loses any effectiveness."	Before-and-after speed and crash data analysis, matched experimental and control sites with speed data analysis [Sparks and Cynecki 1990 (*17*)]	The authors do concede that actuated warning flashers may be beneficial in a high-speed rural environment with unusual geometrics, high pedestrian crossings, and unfamiliar drivers. However, these conditions were not tested in their study.
Advance overhead flashing amber beacons, pole-mounted flashing beacons at crosswalk, pedestrian activation (1 location in Chattanooga, Tennessee)	The original 1987 data collection showed that motorist yielding improved from 11 to 52 percent in the eastbound direction and 6 to 32 percent in the westbound direction. Motorist yielding has been sustained as of 2000, when it was measured to be 55 percent in the eastbound direction and 45 percent in the westbound direction.	Before-and-after motorist compliance study (also includes an "after" period 12 years after installation) [Van Winkle and Neal 2000 (*16*)]	The authors attribute the success of the flashers to the pedestrian activation.
Overhead flashing regulatory sign (with message "STOP FOR PEDESTRIAN IN CROSSWALK"), pedestrian activation (3 locations in Tucson, Arizona)	Motorist yielding declined from 63 to 52 percent. Pedestrians who ran, hesitated, or aborted their crossing decreased from 17 to 10 percent.	Before-and-after motorist compliance and pedestrian behavior study [Huang, Zegeer, and Nassi 2000 (*26*)]	The authors indicated that the Tucson results may have been affected by the installation on high-volume arterial streets with speeds limits of 30 mph (48 km/h), 35 mph (56 km/h), and 40 mph (64 km/h).
Overhead flashing amber beacons, directional scanning eyes, advance stop lines, motorist prompting signs (1 location in St. Petersburg, Florida)	After installation of the flashing beacons and other treatments, motorists yielding to pedestrians increased from 3 to 30 percent. Vehicle-pedestrian conflicts decreased from 2 to 0.5 percent.	Before-and-after motorist compliance and vehicle-pedestrian conflicts study [CUTR 2000 (*14*)]	Multiple crossing treatments were used at this location. The improvements in the MOEs were the second most dramatic found in the study (half-signals had most improvement).

TABLE E-1. Summary of Pedestrian Crossing Treatment Evaluations (continued).

Crossing Treatment(s) and Study Site Location	Reported Effectiveness	Experimental Design [Reference or Study]	Discussion
Overhead flashing amber beacons, passive pedestrian detection and actuation, advance and crosswalk signing and marking (25 locations in Los Angeles, California)	Informal studies by Los Angeles DOT indicate that motorists yielding to pedestrians at sites with overhead flashing beacons is in the 72 to 76 percent range. Motorist yielding at other uncontrolled but marked crosswalks are in the 20 to 30 percent range. Limited data indicate that 85th percentile speeds are reduced by 2 to 12 mph (3 to 19 km/h).	Informal experimental and control site studies [Fisher undated (*15*)]	This treatment is known locally as the "Smart Pedestrian Warning." The flashing beacon uses an alternating flash pattern that uses three flash pulses per half-second followed by a half-second pause.
	In-Roadway Warning Lights		
In-roadway warning lights, pedestrian crossing signs with integral flashing lights (7 locations in California: Fort Bragg, 1; Lafayette, 2; Orinda, 1; Petaluma, 1; Santa Rosa, 1; and Willits, 1)	Considering the effectiveness for all seven locations, average motorists yielding to pedestrians increased from 28 to 53 percent during the daytime and nighttime yielding increased from 13 to 65 percent. The distance at which motorists first begin braking for the crosswalk increased from 133 to 159 ft during the daytime, and from 133 to 210 ft during the nighttime.	Before-and-after motorist compliance and motorist braking behavior [Whitlock and Weinberger Transportation, Inc. 1998 (*84*); also reported in Evans 1999 (*85*); Katz, Okitsu, and Associates 2000 (*86*)]	This appears to be the first comprehensive study of in-roadway warning lights. The authors also provided installation guidelines and criteria.
In-roadway warning lights, median refuge island (2 locations in Kirkland, Washington)	Motorists yielding to pedestrians increased from 56 to 91 percent during the daytime and nighttime yielding increased from 39 to 97 percent. The distance at which motorists first begin braking for the crosswalk increased from 218 to 262 ft during the daytime, and from 190 to 264 ft during the nighttime.	Before-and-after motorist compliance and motorist braking behavior, measured during daytime and nighttime conditions [Whitlock and Weinberger Transportation, Inc. 1998 (*84*); also reported in Godfrey and Mazzella 1999 (*19*); Katz, Okitsu, and Associates 2000 (*86*)]	Kirkland city staff considered the treatment a success, both in terms of increasing driver yielding as well as garnering public support.

TABLE E-1. Summary of Pedestrian Crossing Treatment Evaluations (continued).

Crossing Treatment(s) and Study Site Location	Reported Effectiveness	Experimental Design [Reference or Study]	Discussion
In-roadway warning lights, automated pedestrian detection (1 location in Orlando, Florida)	After installation of the in-roadway warning lights, motorist yielding to pedestrians increased slightly from 7 to 11 percent. Upon activation of the flashing lights, average vehicle speeds decreased from 28 to 27 mph (45 to 43 km/h), a difference that was not significant. At the flashing crosswalk, 60 percent of pedestrians experienced a pedestrian-vehicle conflict. At other control locations, 87 percent of pedestrians had conflicts.	Before-and-after study of vehicle speeds and driver yielding; experimental and control for vehicle-pedestrian conflicts, pedestrian behavior, and pedestrian perception [Huang, Hughes, Zegeer, and Nitzburg 1999 (*55*)]	The location of the study site (adjacent to a 2500 seat theatre) likely had a great deal of influence on the mediocre results. The pedestrian activity is largely event-driven, and pedestrians cross the street en masse at limited times before and after performances. The site could likely benefit from other improvements, such as landscaping or curbside railing to better direct pedestrians to designated street crossings.
In-roadway warning lights (32 locations in California and Washington State)	The authors calculated that crosswalks with traditional pavement markings have an average crash rate of 1 pedestrian crash per 35 million vehicles (184 locations in Santa Ana, California). The comparative crash rate for crosswalks with in-roadway warning lights (32 locations) was 1 pedestrian crash per 214 million vehicles, a crash rate that is 80 percent lower than marked crosswalks.	Retrospective experimental and control crash analysis [Katz, Okitsu, and Associates 2000 (*86*)]	Insufficient information was presented for this analysis to either dispute or confirm the validity of the findings. The crash analysis used vehicle volumes instead of pedestrians, which may not accurately portray exposure.
In-roadway warning lights, automated pedestrian detection (1 location each in Lakeland and Gainesville, Florida)	The two locations produced markedly different results. Driver yielding in Lakeland improved from 18 to 30 percent (though not statistically significant). Driver yielding in Gainesville decreased from 81 to 75 percent. No significant or practical differences were observed for pedestrian behavior.	Before-and-after study of driver yielding and pedestrian behavior [Huang 2000 (*87*)]	The location of the study sites likely influenced the study results. Many older pedestrians were present at Lakeland; thus, the low driver yielding may be due to passive crossing behavior. College-aged pedestrians at the Gainesville site were likely more aggressive and thus received a much higher driver yielding rate.

TABLE E-1. Summary of Pedestrian Crossing Treatment Evaluations (continued).

Crossing Treatment(s) and Study Site Location	Reported Effectiveness	Experimental Design [Reference or Study]	Discussion
In-roadway warning lights, pedestrian crossing signs with integral flashing lights, median refuge island (1 location in Honolulu, Hawaii)	After installation of the in-roadway warning lights and accompanying signs, drivers that either slowed or stopped for pedestrians increased from 30 to 62 percent. The average speeds during flashing light activation decreased 26 percent (from 40 to 30 mph [48 km/h]) and the 85th percentile speeds decreased 15 percent (from 45 to 39 mph [72 to 63 km/h]). Average pedestrian wait time at the curb decreased from 27 to 13 seconds, and the percent of pedestrians who ran during the crossing dropped from 22 to 12 percent.	Before-and-after study of vehicle speeds, pedestrian crossing time, and pedestrian behavior [Prevedouros 2001 (*24*)]	The author considered the treatment a success both in terms of quantitative MOEs as well as favorable motorist and pedestrian perception. The results are notable considering the facility where the treatment was installed. Pali Highway is a seven-lane arterial with 30,000 average daily traffic (ADT) and 85th percentile speeds of 45 mph (72 km/h).
In-roadway warning lights, high-visibility crosswalk marking (2 separate crosswalks at 1 location in Denville, New Jersey)	After installation of the in-roadway warning lights, the average approach speed initially decreased 14 percent but then increased 10 percent above "before" conditions. With installation of high-visibility crosswalk pavement markings, no vehicle-pedestrian conflicts were recorded; however, when in-roadway warning lights were added to the high-visibility crosswalk markings, the conflicts increased slightly, but to a level that is about one-sixth of the "before" condition.	Before-and-after study with escalating improvements, considers motorist and pedestrian behavior, pedestrian perceptions, and crosswalk conspicuity [Boyce and Van Derlofske 2002 (*20*)]	The authors questioned whether the incremental benefits of in-roadway warning lights over high-visibility crosswalk pavement marking justified the additional expense. Several factors could have contributed to the mediocre results of the study: (a) complex intersection geometry at the crossing locations, (b) automated pedestrian detection that operated poorly, and (c) system design limitations that affected pedestrian understanding and device visibility.
	Motorist Warning Signs and Pavement Markings		
"STOP HERE FOR PEDESTRIAN" signs, advance stop line (2 locations in Dartmouth, Nova Scotia [Canada])	After installation of the signs and pavement markings, the average pedestrian-vehicle conflicts declined from 39 to 18 percent. Driver yielding improving from an average of 31 percent to 40 percent with just the sign, and 41 percent with the sign and pavement markings. Driver braking behavior also improved, with significantly more motorists stopping greater distances from the crossing.	Before-and-after study with escalating improvements, considers driver yielding, pedestrian-vehicle conflicts, and driver braking behavior [Van Houten and Malenfant 1992 (*28*)]	Both locations had flashing beacons in place before the experiment. The authors concluded that the signs were equally effective independent of whether the flashing beacons were activated by a pedestrian. Driver yielding was marginally better when the flashing beacons were activated (34 percent yielding) than when the beacons were not flashing (28 percent yielding).

TABLE E-1. Summary of Pedestrian Crossing Treatment Evaluations (continued).

Crossing Treatment(s) and Study Site Location	Reported Effectiveness	Experimental Design [Reference or Study]	Discussion
Overhead flashing amber beacons, animated LED eyes, automated pedestrian detection (1 location in St. Petersburg, Florida)	The installation of the animated LED eyes increased driver yielding from 15 to 62 percent, whereas the flashing beacon only increased yielding from 15 to 36 percent. Pedestrians stranded decreased from 17 to 6 percent for the flashing beacon and 3 percent for the animated LED eyes.	Before-and-after study with alternating treatments, considers driver yielding, pedestrian-vehicle conflicts, and pedestrians stranded in the center of the roadway [Van Houten, Malenfant, and Hochstein 1999 (29)]	The experimental design with alternating treatments could have produced some residual effects, as the animated LED eyes was tested one day and the flashing beacons could have been tested the very next day. It is not clear whether the authors addressed these residual effects in this study.
Advance stop lines, motorist prompting signs, pedestrian prompting signs (4 locations in St. Petersburg, Florida)	Average driver yielding improved slightly from 2 to 3 percent (likely not statistically significant). Pedestrian-vehicle conflicts had similar small improvements and, on average, declined from 3 to 0 percent.	Before-and-after motorist compliance and vehicle-pedestrian conflicts study [CUTR 2000 (*14*)]	Multiple crossing treatments were used at these locations. Although the engineering treatments were part of a multidisciplinary approach, the authors did not isolate the effects of concurrent education or enforcement activities.
Overhead "CROSSWALK" warning sign (1 location in Seattle, Washington)	Motorist yielding increased from 46 to 52 percent (statistically significant). Pedestrians who ran, hesitated, or aborted their crossing decreased from 58 to 43 percent.	Before-and-after motorist compliance and pedestrian behavior study [Huang, Zegeer, and Nassi 2000 (*26*)]	The sign was installed on a two-lane, one-way street posted for 30 mph (48 km/h) speed limit.
In-roadway pedestrian crossing sign (mounted on cone) (6 locations in New York State; 1 location in Portland, Oregon)	Average motorist yielding improved from 70 to 81 percent. Pedestrians who ran, hesitated, or aborted their crossing decreased slightly from 35 to 33 percent.	Before-and-after motorist compliance and pedestrian behavior study [Huang, Zegeer, and Nassi 2000 (*26*)]	All locations were posted for 30 mph (48 km/h) speed limit. Five of the locations were two-lane streets; one was a three-lane, and the other was a four-lane undivided street.
Overhead illuminated "CROSSWALK" warning sign, high-visibility crosswalk pavement markings (2 locations in Clearwater, Florida)	Daytime driver yielding averaged 35 percent at experimental sites and 3 percent at control sites. Nighttime yielding was 18 percent at one of the experimental sites and 12 percent at one of the control sites (difference not statistically significant).	Matched experimental and control sites, considers driver yielding, pedestrian behavior, and pedestrian-vehicle conflicts [Nitzburg and Knoblauch 2001 (*25*)]	Pedestrian looking behavior and forced right-of-way showed no significant differences between the experimental and control sites, indicating the treatments did not increase the pedestrians' "false sense of security."

TABLE E-1. Summary of Pedestrian Crossing Treatment Evaluations (continued).

Crossing Treatment(s) and Study Site Location	Reported Effectiveness	Experimental Design [Reference or Study]	Discussion
Advance yield pavement markings and signs, overhead flashing amber beacons (3 locations in Halifax, Nova Scotia [Canada])	After installation of the signs and pavement markings, average pedestrian-vehicle conflicts declined from 15 to 3 percent. Driver yielding improved from an average of 85 percent to 92 percent. Driver yielding behavior at greater distances from the crosswalk also improved, with significantly more motorists stopping greater distances from the crossing.	Before-and-after study with multiple "after" scenarios, considers driver yielding, pedestrian-vehicle conflicts, and driver braking behavior [Van Houten, Malenfant, and MCusker 2001 (*29*)]	The authors did not evaluate the individual contribution of the flashing beacons to the treatment effectiveness, but seemed to indicate that the advance yield markings and signs were largely responsible for any improvements.
Advance yield pavement markings and signs, fluorescent yellow-green crossing signs (24 locations in Nova Scotia, Canada)	Pedestrian-vehicle conflicts decreased from 12 to 2 percent, while motorist yielding increased from 69 to 85 percent. Yielding at 10 ft (3 m) before the crossing increased from 37 to 83 percent and yielding at 20 ft (6 m) before the crossing increased from 13 to 54 percent. The use of the yellow-green crossing signs had no significant impacts on the MOEs.	Before-and-after study with three different treatment groups plus a control group; considers driver yielding, pedestrian-vehicle conflicts, and driver braking behavior [Van Houten, McCusker, Huybers, Malenfant, and Rice-Smith 2002 (*88*)]	All streets in the study were posted at 30 mph (48 km/h), and the authors cautioned the use of these treatments on streets posted 40 mph (64 km/h) or greater. Pedestrian-activated flashing beacons were already in place at 19 of the 24 locations, and 3 additional locations had flashing beacons installed during the "after" period. The authors indicated that the flashing beacons may have contributed to the driver yielding rate.
	Crosswalk Pavement Markings		
Crosswalk pavement markings (400 locations in San Diego, California)	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 2 to 3 times as many crashes in marked crosswalks as in unmarked crosswalks.	Retrospective matched experimental and control crash analysis (5 years of crash data for marked and unmarked crosswalks) [Herms 1970 (*39*); Herms 1972 (*40*)]	Many have criticized this study as leading to the removal of pedestrian accommodation on city streets. Many now think that crosswalk markings should not be removed in these cases, but supplemented with various other types of safety treatments that enable pedestrians to cross busy roadways.
Crosswalk pavement markings (380 locations in California)	After accounting for pedestrian exposure, Crash rates at marked crosswalks were 3.2 to 3.7 times higher than crash rates at unmarked crosswalks for the unsignalized intersections.	Retrospective experimental and control crash analysis (5 years of crash data) [Gibby, Stites, Thurgood, and Ferrara 1994 (*37*)]	

TABLE E-1. Summary of Pedestrian Crossing Treatment Evaluations (continued).

Crossing Treatment(s) and Study Site Location	Reported Effectiveness	Experimental Design [Reference or Study]	Discussion
Removal of crosswalk pavement markings (104 locations in Los Angeles, California)	Considering crashes at both marked and unmarked legs of the intersections at which the marked crosswalk was removed, the number of pedestrian-vehicle crashes declined from 116 to 31 for equivalent time periods, a 61 percent decline. At adjacent intersections where crosswalk markings were reinstalled after pavement resurfacing, the pedestrian-vehicle crashes increased slightly from 27 to 30, thus indicating that the reduction in crashes at removed crosswalks was not simply being transferred to adjacent marked crosswalks.	Retrospective before-and-after crash analysis (before and after periods were matched for length and ranged from 36 to 111 months) [Jones and Tomcheck 2000 (*35*)]	The authors performed statistical significance testing and found the crash reductions at the removed crosswalks to be significant.
Crosswalk pavement markings (6 locations in Arizona, Maryland, and Virginia)	The crosswalk markings had a very modest effect on vehicle speeds, which decreased on average by 0.2 to 2 mph (0.3 to 3.2 km/h). However, the largest speed decrease (2 mph [3.2 km/h]) was measured when no pedestrians were present, implying that motorists slowed simply because of the presence of crosswalk markings. The other statistically significant speed decrease (1.5 mph [2.4 km/h]) was measured for the condition of pedestrian not looking.	Before-and-after study of vehicle speeds for different staged pedestrian behaviors [Knoblauch and Raymond 2000 (*34*)]	The study results are counter-intuitive, in that the largest speed reduction was obtained when no staged pedestrians were present. Additionally, the implications of a 2 mph (3.2 km/h) speed reduction near crosswalks are most likely negligible for pedestrian safety.
Crosswalk pavement markings (11 locations: 3 in Sacramento, California; 3 in Richmond, Virginia; 3 in Buffalo, New York; and 2 in Stillwater, Minnesota)	Speed reductions were very modest at the study locations (on average, less than 1 mph [1.6 km/h]). No significant changes were noted for driver yielding . Similarly, there were no changes in blatantly aggressive pedestrian behavior.	Before-and-after study of vehicle speeds for staged pedestrian behaviors, driver yielding behavior, and pedestrian behavior [Knoblauch, Nitzburg, and Seifert 2001 (*36*)]	The authors suggested that very modest speed reductions indicated that motorists were aware of the marked crosswalks.

TABLE E-1. Summary of Pedestrian Crossing Treatment Evaluations (continued).

Crossing Treatment(s) and Study Site Location	Reported Effectiveness	Experimental Design [Reference or Study]	Discussion
Crosswalk pavement markings (1000 locations in 16 states)	Crash rates at marked crosswalks were not significantly different than unmarked crosswalks on two-lane roads. On multilane roads with high traffic volumes, the pedestrian crash rate in marked crosswalks was 4 to 5 times higher than in unmarked crosswalks. Median refuge islands were associated with a lower crash rate than similar multilane divided roadways.	Retrospective matched experimental and control site crash analysis [Zegeer, Stewart, and Huang 2002 (*31*)]	The authors' recommendations include a matrix that indicates under what conditions (i.e., geometry, speed, traffic volume) marked crosswalks ALONE are insufficient and other pedestrian crossing improvements are needed.
Crosswalk pavement markings (282 locations in California and Washington State)	After adjusting for the various traffic and pedestrian characteristics, the risk of a pedestrian-vehicle crash was 3.6 times greater at uncontrolled intersections with a marked crosswalk.	Retrospective matched experimental and control site crash analysis [Koepsell, McCloskey, Wolf, Moudon, Buchner, Kraus, and Patterson 2002 (*33*)]	These study results generally agree with those of Herms 1970 and Zegeer 2002.
Design Elements			
Median refuge islands (10 locations in Toronto, Canada)	The crash rate was significantly higher for split pedestrian crossovers (i.e., refuge island with signal control) than for pedestrian refuge islands with no signal control. The authors found significantly more vehicle-vehicle crashes at the split crossovers, but more vehicle-island and vehicle-pedestrian crashes at pedestrian refuge islands.	Retrospective experimental and control site crash analysis [Bacquie, Egan, and Ing 2001 (*42*)]	

APPENDIX F

PEDESTRIAN CROSSING INSTALLATION GUIDELINES

This Appendix summarizes pedestrian crossing installation criteria used by entities from several countries. These criteria are used to determine where and what type of pedestrian crossings are to be installed on various types of facilities. Some entities have developed formal “warrants,” whereas others have identified guidelines. In addition, some countries list the factors that should be taken into consideration when considering installation of pedestrian crossings.

UNITED STATES OF AMERICA

Guidelines from Recent Publications

De Robertis and Ridgway (*89*) summarized where marked crosswalks are generally used:

- At signalized intersections with pedestrian signal indications or substantial pedestrian crossings;
- Where marked crosswalks can concentrate or channelize multiple pedestrian crossings to a single location;
- Where there is a need to delineate the optimal crossing location when it is unclear because of unusual geometric layout, sight distance, or traffic operations;
- At approved school crossings or for crossings on suggested safe routes to school; and
- At other locations with significant pedestrian crossings and potential for pedestrian-vehicle conflicts.

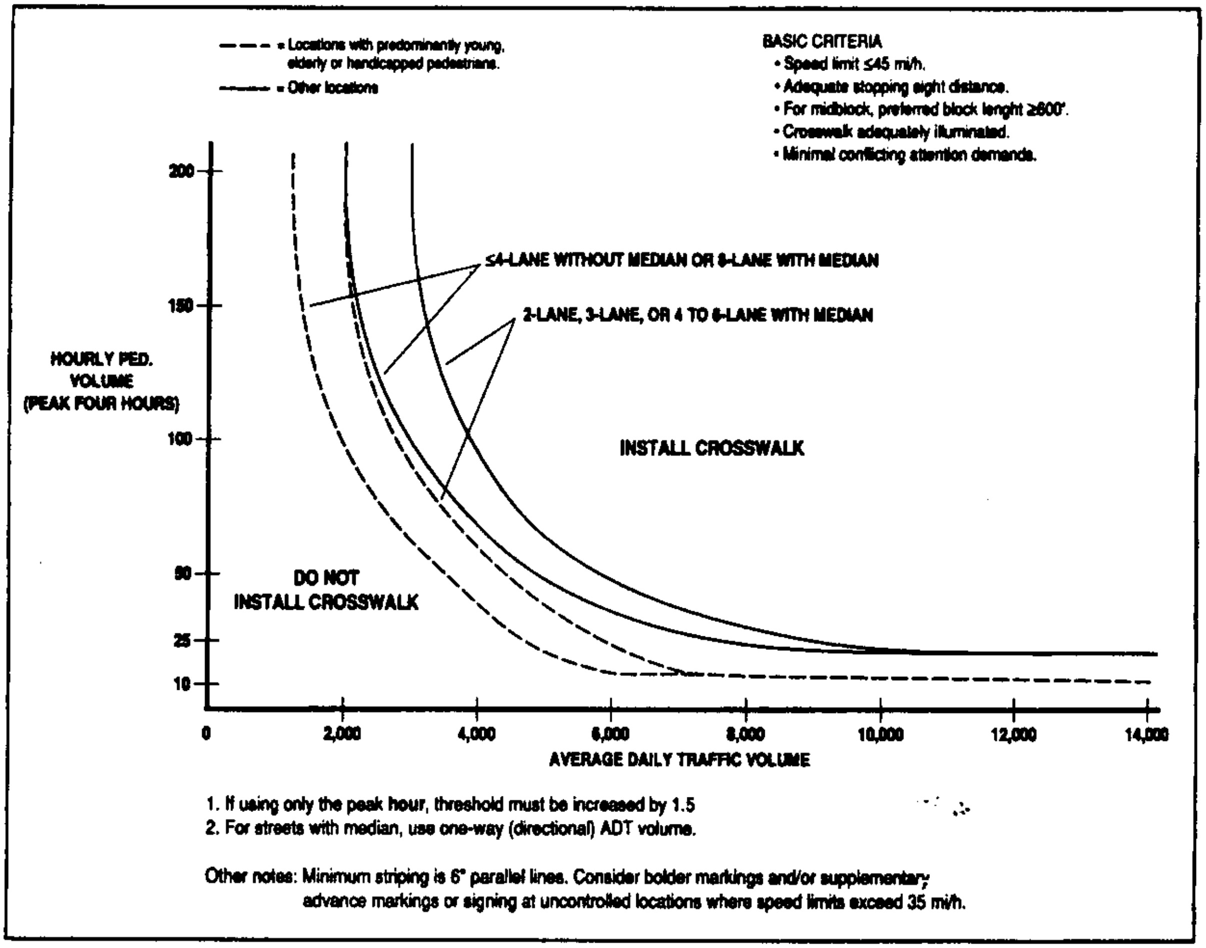
Marked crosswalks potentially suffer from the following drawbacks if minimal treatments are used to mark and sign the crosswalk:

- May make pedestrians feel overconfident,
- May cause a greater number of rear-end collisions,
- May cause an increase in the number of fatal or serious-injury collisions, or
- May result in costly maintenance.

Installation of midblock crosswalks is considered when:

- Protected intersection crossings are more than 590 ft (180 m) apart, 328 ft (100 m) in high-pedestrian volume locations,
- Adequate sight distance is available, and
- The combination of traffic and pedestrian volumes justify the installation.

Figure F-1 was developed as a guide to be used for installing crosswalks at uncontrolled and midblock crossing and is included in the ITE Recommended Practice on Design and Safety of Pedestrian Facilities (*90*).



1 mi = 1.61 km

Figure F-1. Guidelines for Installing Crosswalks at Uncontrolled and Midblock Crossings (90).

MUTCD Discussions

The *MUTCD* (*1*) provides warrants for installing traffic control signals based on the volume of 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.

Although the *MUTCD* 2001 Edition (*91*) addresses the installation of accessible pedestrian signals (APS) for people with visual impairments, it should be noted that un-signalized crossing locations are difficult or impossible for pedestrians who are blind or visually impaired to utilize safely, especially in areas where there are significant through movements. Current methods of gap determination do not consider the needs of pedestrians who use hearing, rather than vision, to determine gaps in traffic.

Preliminary research yet to be published indicates that auditory gap detection may require gaps in traffic that are 3 or more seconds longer than visual gap detection. Uncontrolled crossings having gaps sufficient to allow sighted pedestrians time to cross may not permit blind pedestrians to do so. This is especially the case if other sounds mask the noise of vehicles stopping for pedestrians in the crosswalk, making it impossible for blind pedestrians to ascertain if all vehicles have stopped to permit a safe crossing. This is particularly so for crosswalks across multilane facilities.

Federal Highway Administration Study (*31*)

The objective of an FHWA study, conducted by the University of North Carolina, was to compare pedestrian collision occurrence at marked versus unmarked crosswalks at uncontrolled intersections throughout the United States. Data studied were summarized to provide the following information:

Study Sites

- 1000 marked and 1000 unmarked crossings were selected from 30 cities across the country.
- School crossings were excluded.
- Midblock locations were excluded.

Data Collection

- Data included collision history (5 years), pedestrian volume estimates, traffic volumes, number of lanes, speed limit, median and crosswalk types for each location.
- Pedestrian-related collision data included 229 pedestrian collisions in the sample.

Key findings are listed below. Guidelines were developed based on these findings and are shown in Table F-1.

- Two-lane roads: no significant difference between marked and unmarked crosswalks.
- Multilane roads with ADT below 12,000: no significant difference between marked and unmarked crosswalks.
- Multilane roads with ADT above 12,000 and no raised median: marked crosswalks had significantly higher pedestrian collision rates than unmarked crosswalks.
- Multilane roads with ADT above 15,000 and with raised median: marked crosswalks had significantly higher pedestrian collision rates than unmarked crosswalks.
- Regional effects: higher pedestrian collision rates were found in western U.S. cities compared to eastern U.S. cities.
- Variables having no effect: area type, speed limit, one-way versus two-way, crosswalk condition, and marking pattern had no effect on the occurrence of pedestrian collisions. Pedestrian volumes were not measured.
- Multiple-threat collisions: 17.6 percent of the collisions in marked crosswalks were multiple-threat collisions (i.e., one vehicle stops for the pedestrian but the driver in the adjacent lane does not see the pedestrian). None occurred in unmarked crosswalks.
- Collision severity: six fatalities occurred in marked crosswalks and zero in unmarked crosswalks (out of 229 total collisions in the sample).

TABLE F-1. Guidelines for Marked Crosswalk Installation (for Uncontrolled Intersections) (*31*).

	≤9,000 ADT			>9,000 to ≤12,000 ADT			>12,000 to ≤15,000 ADT			> 15,000 ADT		
	≤30 mph (48 km/h)	35 mph (56 km/h)	≥40 mph[b] (64 km/h)	≤30 mph (48 km/h)	35 mph (56 km/h)	≥40 mph[b] (64 km/h)	≤30 mph (48 km/h)	35 mph (56 km/h)	≥40 mph[b] (64 km/h)	≤30 mph (48 km/h)	35 mph (56 km/h)	≥40 mph[b] (64 km/h)
2 Lanes												
3 Lanes												
++4 Lanes, raised median[c]												
++4++ Lanes, no median												

Key

Candidate sites for marked crosswalks alone.

Probable candidate sites for marked crosswalks. The use of other pedestrian facility enhancements should be evaluated. These locations should be closely monitored and may be considered for enhancements as feasible.

Marked crosswalks alone are insufficient. The use of other pedestrian facility enhancements is recommended. These locations should be considered for marking only after the appropriate enhancements are determined.

a. These guidelines include intersection and midblock locations without traffic signals, beacons, or STOP or YIELD signs on the approach to the crossing. They do not apply to school crossings. These are general recommendations; good engineering judgment should be used in individual cases for deciding when to install a marked crosswalk. It is recommended that a minimum of 20 pedestrian crossings per vehicular peak hour (or 15 or more pedestrians in special population groups, e.g., elderly and/or child pedestrians) exist at a location before considering the installation of a marked crosswalk.

b. Where the posted speed limit exceeds 40 mph (64 km/h), marked crosswalks should not be used at locations not controlled by a signal, beacon, STOP or YIELD sign, and/or other enhancements.

c. The raised median or refuge island must be approximately 5 ft (1.2 m) wide and 6 ft (1.8 m) long in the direction of pedestrian travel to adequately serve as a refuge area for pedestrians.

Local Agencies

The city of San Luis Obispo, California, has adopted a formal policy on where marked pedestrian crossings are to be provided. The completed policy is provided in Table F-2. The in-pavement flashing markers installation criteria could be adapted for the development of national guidelines.

TABLE F-2. Guidelines for the Installation of Marked Crosswalks Used in San Luis Obispo, California.

To establish formal procedures where pedestrian crosswalks, pedestrian traffic control warning devices, and other miscellaneous pedestrian control devices other than traffic signals are installed, a number of agencies, such as San Luis Obispo, California, U.S.A., have developed the following guidelines:

a. General

A crosswalk is a unique traffic control device. It can be marked or unmarked. Crosswalk markings should not be used indiscriminately because it has been shown that pedestrians may develop a false sense of security regarding their use of a marked location. However, a marked crosswalk should be installed where an engineering study is performed that determines if marked crosswalks are appropriate at locations that are not controlled by traffic signals, flashing beacons or stop signs.

b. Installation of Marked Crosswalks on Uncontrolled Approaches of Intersections

Based on industry standards in both the 'Manual of Uniform Traffic Control Devices' and criteria that have been successful in other similar jurisdictions, the following guidelines should be used to determine appropriateness of marked crosswalks on public streets. Marked crosswalks may be considered for installation at uncontrolled locations if the following requirements are met:

- The pedestrian volume is 40 or more per hour during the peak hour of pedestrian usage, or
- There are 30 groupings of two or more pedestrians for a continuous 2-hour period twice a day, and
- The 85th percentile approach speed is below 40 mph (64 km/h), and
- The roadway has less than three travel lanes in one direction, and
- The proposed crosswalk has adequate lighting for nighttime visibility (if the location satisfies all other criteria the City shall install street lighting as part of the crosswalk installation), and
- There is an unrestricted visibility of the crosswalk for a minimum distance as listed below.
- If residential, the roadway conducts 2,700 ADT or more, and
- There is no controlled crosswalk (by a traffic signal or stop sign) within one block (660 ft [201 m]) of the proposed crosswalk.

Minimum Sight Distance for the Placement of Crosswalks.

Design Speed, mph (km/h)	Minimum Sight Distance, ft (m)	Design Speed, mph (km/h)	Minimum Sight Distance, ft (m)
20 (32)	125 (38)	45 (72)	360 (110)
25 (40)	150 (46)	50 (81)	430 (131)
30 (48)	200 (61)	55 (89)	500 (153)
35 (56)	250 (76)	60 (97)	580 (177)
40 (64)	300 (92)	65 (105)	660 (201)

TABLE F-2. Guidelines for the Installation of Marked Crosswalks Used in San Luis Obispo, California (continued).

Installation of a marked crosswalk(s) may be authorized that does not satisfy all of the criteria in Section B if it is deemed that, based on analysis, other unique circumstances warrant the installation of the marked crosswalk. The circumstances include but are not limited to: school pedestrian crosswalks on an approved 'Safe Route to School Map,' channelization of pedestrians to a single point of crossing, or otherwise clarify the appropriate place for a safer crossing.

All marked crosswalks installed at uncontrolled locations should be 'high-visibility' ladder type crosswalks.

c. Installation of Marked Crosswalks Between Intersections (Midblock)

A midblock marked crosswalk may be installed if it meets the requirements of Section B, and all of the following:

- The length of the block between intersections is greater than 660ft; and
- There is reasonable demand by pedestrians, as demonstrated by an engineering survey, to cross within a concentrated area that is 200 ft (61 m)or greater from the nearest signal or stop sign controlled intersection; and
- There is a high pedestrian volume generator nearby.

Installation of a marked crosswalk(s) may be authorized that does not satisfy all of the criteria in this section if it is deemed that, based on analysis, other unique circumstances warrant the installation of the marked crosswalk. (see Section b for examples)

d. Reinstallation of Marked Crosswalks Covered by Roadway Surfacing

The reinstallation of marked crosswalks should be evaluated as part of all roadway surface treatment projects that cover up pavement markings (slurry seal, chip seal, and overlay). All marked crosswalks that do not meet the criteria should be considered for removal to alternative treatments described in this report.

e. Marked Crosswalk Removal

Subject to the completion of an engineering study, existing crosswalk markings may be removed if one or more of the requirements of Section b or c are not met.

f. High-Visibility Crosswalks

High-visibility ladder type crosswalks should be marked at uncontrolled marked crosswalks or where it is determined that their use will benefit marked crosswalk effectiveness at crosswalks controlled by traffic signals or stop signs.

g. Marked Crosswalks at Traffic Signal Locations

Marked crosswalks should be installed at all designated crosswalks at intersections controlled by traffic signals. These crosswalk markings should be 12 inches (35 cm) white or yellow markings and spaced a minimum of 10 inches (25 cm) apart. Crosswalks shall not be marked at locations where pedestrian crossings are prohibited for safety or operational reasons. In these instances, appropriate signage prohibiting the crossing and instructing pedestrians to the appropriate crossing locations should be erected.

h. School Crosswalks

School crosswalks are to be established at appropriate crossing locations on the approved 'Suggested Route to School' map. Warrants and locations of the school crosswalks shall be based on recommended guidelines as contained in the Manual of Uniform Traffic Control Devices (*MUTCD*).

TABLE F-2. Guidelines for the Installation of Marked Crosswalks Used in San Luis Obispo, California (continued).

i. Traffic Control Devices for Crosswalks

Traffic control devices for crosswalks should be installed per the *MUTCD*. Where discrepancies exist for the proper installation of advanced traffic control devices, appropriate signing and warning combinations, on a case-by-case basis should handle these.

j. In-Road Pavement Lighting for Crosswalks

In-road crosswalk lighting incorporates the use of lights that are imbedded in the pavement, similar to lights used in the runways of airports. Their use has been proven effective in certain locations particularly for multilane majors that have limited visibility of pedestrians. However, their use should be limited to only those where in-ground pavement lighting will promote visibility of pedestrians more effectively than other warning devices that have proven ineffective in advising motorists of crosswalk occupation.

In-road pavement lighting may be considered at uncontrolled locations if the following requirements are met:

1. The pedestrian volume is 100 or more per hour for a period of any four hours of the day, or there are 100 groupings of two or more pedestrians for a continuous 2-hour period twice a day, and
2. The pedestrian volume after dark is 75 or more for any one hour, or 25 or more for a period of any four hours during the night-time, and
3. The roadway conducts 10,000 ADT or more, and
4. The 85th percentile approach speed is 35 mph (56 km/h) or less, and
5. The roadway has two or more vehicular travel lanes in one direction but not more than four through lanes in both directions, and
6. The crosswalk is not controlled by a traffic signal, stop or yield sign.

Specifications for the installation of in-road pavement lighting shall be in accordance with established industry standards. The specifications should consider the following: automatic Activation (passive detection), adjustable light orientation and levels of illumination, accompaniment of appropriate advance warning signage that could include the use of ‘smart’ signs alerting motorists of pedestrian activity, and ability to be easily maintained.

The city of Sacramento, California, has developed a set of Pedestrian Safety Guidelines (*92*) which includes charts summarizing the type of crossing treatments appropriate on different streets. The charts are provided in Tables F-3 through F-6.

TABLE F-3. Guidelines for the Installation of Pedestrian Crossing Treatments for Sacramento, California – Two-Lane Streets.

Number of Cars (average daily traffic)	**Posted Speed**		
	30 mph (48 km/h) or less	**35 mph (56 km/h)**	**40 mph (64 km/h) or more**
Up to 15,000 cars per day	Triple-four	Triple-four	Triple-four plus a pedestrian refuge, overhead flashing beacons, or other Level 1 and 2 devices
15,000 cars or more per day		Triple-four plus a pedestrian refuge, overhead flashing beacons, or other Level 1 and 2 devices	Pedestrian signal or bridge

TABLE F-4. Guidelines for the Installation of Pedestrian Crossing Treatments for Sacramento, California – Three-Lane Streets.

<table>
<tr><th rowspan="2">Number of Cars (average daily traffic)</th><th colspan="3">Posted Speed</th></tr>
<tr><th>30 mph (48 km/h) or less</th><th>35 mph (56 km/h)</th><th>40 mph (64 km/h) or more</th></tr>
<tr><td>9,000 cars or fewer per day</td><td rowspan="2">Triple-four</td><td>Triple-four</td><td rowspan="2">Triple-four plus a pedestrian refuge, overhead flashing beacons, or other Level 1 and 2 devices</td></tr>
<tr><td>9,000-12,000 cars per day</td><td rowspan="2">Triple-four plus a pedestrian refuge, overhead flashing beacons, or other Level 1 and 2 devices</td></tr>
<tr><td>12,000-15,000 cars per day</td><td rowspan="2">Triple-four plus a pedestrian refuge, overhead flashing beacons, or other Level 1 and 2 devices</td><td rowspan="2">Pedestrian signal or bridge</td></tr>
<tr><td>15,000 cars or more per day</td><td>Pedestrian signal or bridge</td></tr>
</table>

TABLE F-5. Guidelines for the Installation of Pedestrian Crossing Treatments for Sacramento, California – Four or More Lanes with a Raised Median.

Number of Cars (average daily traffic)	Posted Speed		
	30 mph (48 km/h) or less	**35 mph (56 km/h)**	**40 mph (64 km/h) or more**
9,000 cars or fewer per day	Triple-four	Triple-four	Triple-four plus a pedestrian refuge, overhead flashing beacons, or other Level 1 and 2 devices
9,000-12,000 cars per day		Triple-four plus a pedestrian refuge, overhead flashing beacons, or other Level 1 and 2 devices	Pedestrian signal or bridge
12,000-15,000 cars per day	Triple-four plus a pedestrian refuge, overhead flashing beacons, or other Level 1 and 2 devices		
15,000 cars or more per day	Pedestrian signal or bridge	Pedestrian signal or bridge	

TABLE F-6. Guidelines for the Installation of Pedestrian Crossing Treatments for Sacramento, California – Four or More Lanes without a Raised Median.

Number of Cars (average daily traffic)	Posted Speed		
	30 mph (48 km/h) or less	**35 mph (56 km/h)**	**40 mph (64 km/h) or more**
9,000 cars or fewer per day	Triple-four	Triple-four plus a pedestrian refuge or other Level 1 device	Triple-four plus a pedestrian refuge, overhead flashing beacons, or other Level 1 and 2 devices
9,000-12,000 cars per day	Triple-four plus a pedestrian refuge or other Level 1 device	Triple-four plus a pedestrian refuge, overhead flashing beacons, or other Level 1 and 2 devices	
12,000-15,000 cars per day	Triple-four plus a pedestrian refuge, overhead flashing beacons, or other Level 1 and 2 devices		Pedestrian signal or bridge
15,000 cars or more per day	Pedestrian signal or bridge	Pedestrian signal or bridge	

CANADA

Transportation Association of Canada

The Transportation Association of Canada has published a *Pedestrian Crossing Control Manual* (*93*) that includes a flow chart for selecting pedestrian treatments (see Figure F-2). The manual lays out warrants for various types of pedestrian crossing control, which are summarized below.

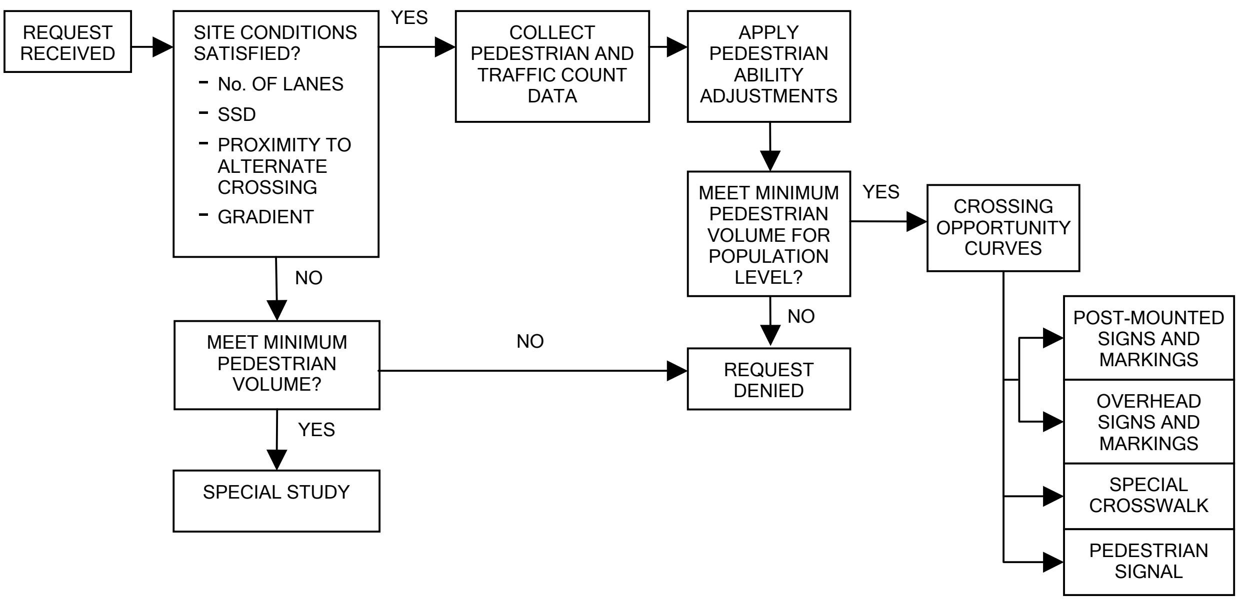


Figure F-2. Warrant Model Flow Chart (adapted from 93).

Determine Pedestrian Volumes

Pedestrian volumes are converted into equivalent adult units (EAUs) where children, seniors, and disabled are given preferential treatment to account for their higher vulnerability (see Table F-7).

TABLE F-7. Equivalent Adult Units (*93*).

Number	Factor	EAUs
Children __________	x 2.0	= _____________
Seniors __________	x 1.5	= _____________
Disabled __________	x 2.0	= _____________
Adults __________	x 1.0	= _____________

Total EAUs in the 1-hour assessment period = __________________

Calculate Crossing Opportunities. Consider the following points in calculating crossing opportunities (COs):

1. If available, the actual number of COs counted in the 1-hour assessment period should be used.
2. If gap data are not available, estimate COs using traffic counts as follows:
   a. Determine traffic volume in the 1-hour assessment period.
   b. Determine traffic arrival pattern. This pattern is a function of the coordination of the traffic signals on either side of the study location. Below are three patterns that can be determined through the use of a time-space diagram:

Pattern A:
Choose curve A if there are no signals within 0.6 mi (1 km) of the study location.

Pattern B:
Choose curve B if signals are uncoordinated, or if the total time occupied by the green bands at the crossing location is more than 50 percent of the cycle length.

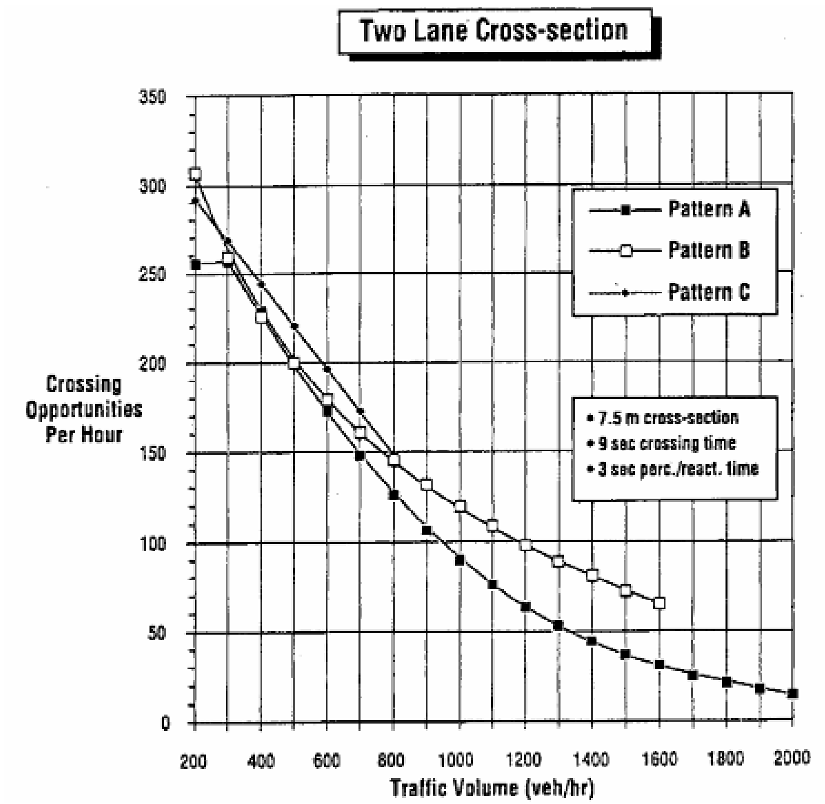
Pattern C:
Choose curve C if the total time occupied by the green bands at the crossing location is less than 50 percent of the cycle length.

   c. Refer to Figures F-3 to F-6.

Adjustment Factor – Community Size. The concentration of pedestrians at a particular crossing is a function of the adjacent land uses and, hence, community sizes. In large urban centers, a high concentration of pedestrians is frequently found, while, in comparison, concentrations of pedestrians in villages and towns could be considerably lower. To reflect this situation, the pedestrian volume base threshold level is decreased for smaller communities so that a traffic control device is recommended sooner than would otherwise be considered.
The adjustment of the EAU threshold must be based on the metropolitan population rather than the municipality population (see Table F-8).

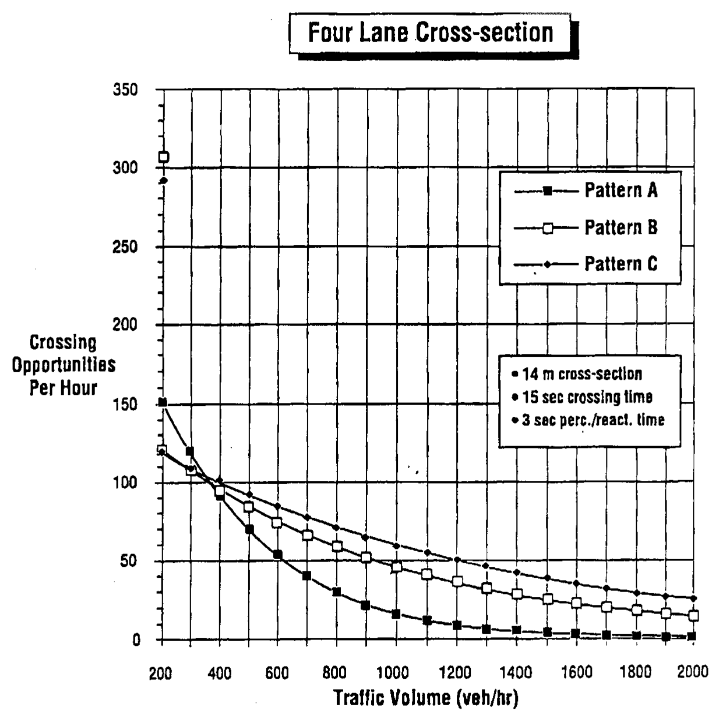
TABLE F-8. Community Size Adjustment Factor (*93*).

Community Size Threshold	Adjustment to EAU
< 10,000	-10.0
10,000-250,000	-5.0
> 250,000	0.0



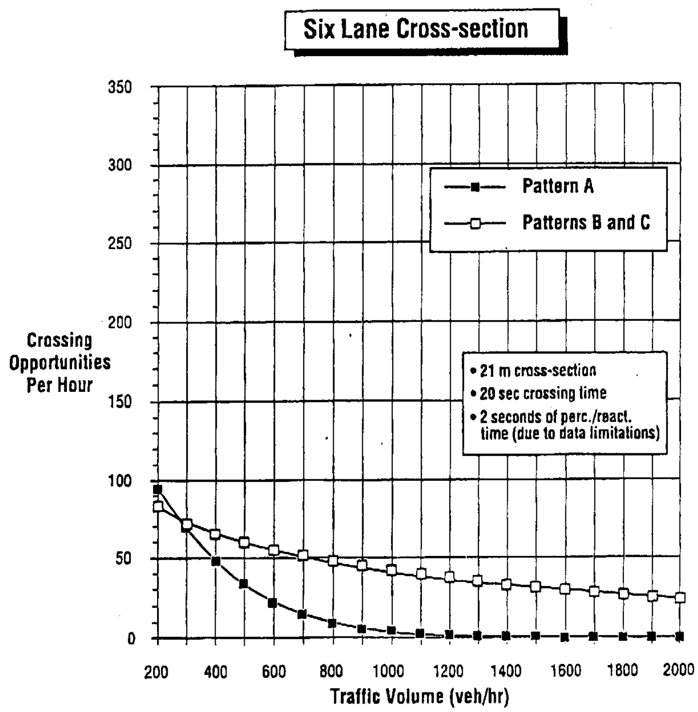
1 ft = 0.305 m

Figure F-3. Estimated Crossing Opportunities for a Two-Lane Cross Section (93).



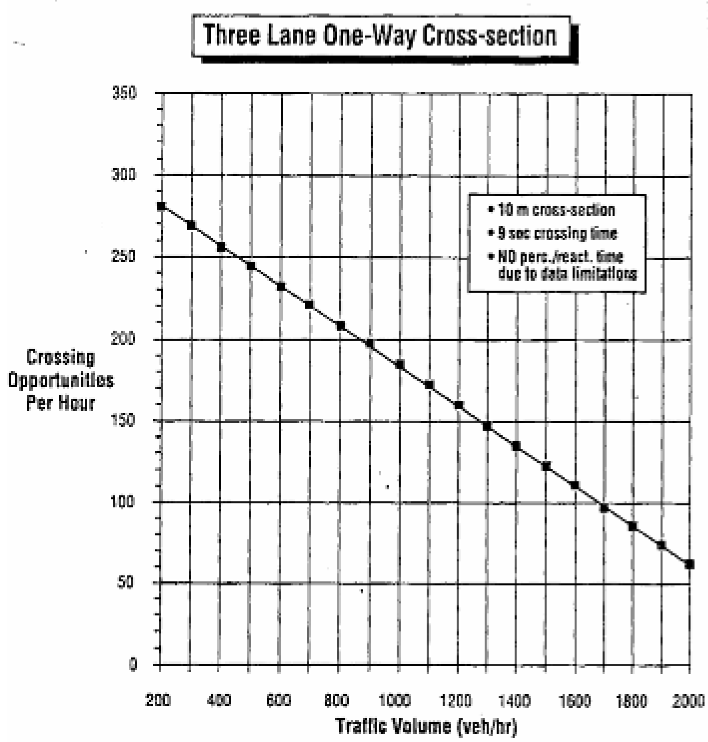
1 ft = 0.305 m

Figure F-4. Estimated Crossing Opportunities for a Four-Lane Cross Section (93).



1 ft = 0.305 m

Figure F-5. Estimated Crossing Opportunities for a Six-Lane Cross Section (93).



1 ft = 0.305 m

Figure F-6. Estimated Crossing Opportunities for a Three-Lane One-way Cross Section (93).

Select Warranted Device. Select the appropriate traffic control device from the warrant chart using COs and EAUs in Figure F-7.

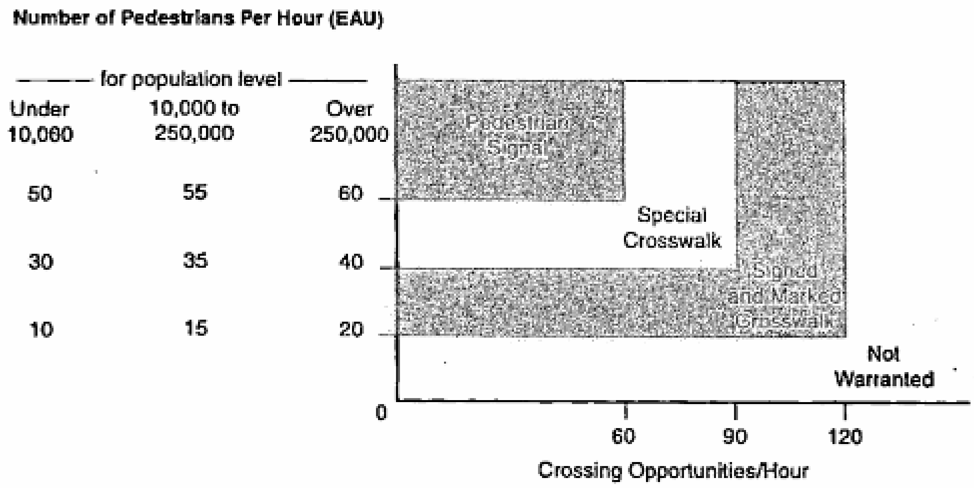


Figure F-7. Pedestrian Crossing Control Warrant Chart (93).

Accident History. While pedestrian accidents are not included as a direct component of the warrant model, the analyst should include a review of the accident history as part of the study of pedestrian crossing needs at the study location.

Province of Ontario

The Ontario *Manual on Uniform Traffic Control Devices* (*94*) provides a specific warrant for midblock pedestrian signals. Under free-flow conditions, the warrant requires an average of 120 pedestrian crossings per hour over the heaviest 8 hours of the day and an average of 290 vehicles per hour (veh/h) entering the crossing over the same 8 hours. Under restricted flow conditions, the warrant values are 240 pedestrians per hour (ped/h) and 575 veh/h. The vehicular volume thresholds are increased by 25 percent for streets with more than one lane per direction.

UNITED KINGDOM OF GREAT BRITAIN (U.K.)

Local Transport Note 1/95 (*95*) entitled "The Assessment of Pedestrian Crossings" identifies the process used in the United Kingdom for when the following types of pedestrian crossing treatments are used:

- Pedestrian refuge islands,
- Zebra crossings (marked uncontrolled crosswalks with high-visibility ladder-style markings), and
- Signal-controlled crossings—Pelican, Puffin, and Toucan. Pelicans and Puffins are pedestrian crossings used at midblock locations primarily in the U.K. and Australia. Pelicans minimize delay to the driver by displaying a flashing amber vehicular indication

during the pedestrian clearance interval, and drivers may proceed if there is no pedestrian in front of them in the crossing. Puffins use detectors to minimize delay to drivers while providing a controlled pedestrian crossing. Toucans provide separated indications for pedestrians and bicyclists. The bicycle indications are actuated when appropriate.

The following checklist is used to analyze sites.

- **Site Characteristics**. Site assessment methodology takes into account the following:
  - Number of lanes/one way or two way,
  - Roadway width,
  - Sidewalk width,
  - Street lighting,
  - Sight distance,
  - Parking restrictions,
  - Bus stops,
  - Distance to nearest intersection,
  - Distance to nearest adjacent crossing and type of crossing,
- **Skid Resistance of Pavement**, and
- **Surrounding Pedestrian Generating Land Uses**.

- **Crossing Traffic Information:**
  - Flow and composition of pedestrians (elderly, strollers or prams, young children, visually impaired, bicyclists, equestrians, wheelchairs),
  - Time to cross road (elderly, able, or disabled),
  - Difficulty of crossing (elderly, able, or disabled), and
  - Latent crossing demand.

- **Vehicle Traffic Information:**
  - Vehicle count,
  - Cyclists,
  - Trucks,
  - Buses, and
  - Vehicle speeds (limit and 85th percentile).

- **Road Collisions:**
  - Number per year, and
  - Average at similar local sites.

Local Transport Note 1/95 (*95*) provides sample assessment frameworks to show how the checklist information should be used to determine the type of treatment that is appropriate for a particular location. The U.K. methodology avoids use of warrants in its methodology, preferring to lay out a site assessment process that leads to the selection of the most appropriate crossing treatment.

NEW ZEALAND

A pedestrian crossing is warranted if during a normal weekday, the flows taken over **any 1-hour period** meet the following criteria:

- The product of the number of pedestrians and the number of vehicles should exceed 45,000, and
- The number of vehicles is not less than 300.

However, many authorities in New Zealand make use of AUSTROADS (Australian) standard AS 1742.10, in which the following criteria should be met:

- Pedestrian flows > 60 ped/h,
- vehicle flows > 600 veh/h, and
- the product of the two > 90,000.

The Christchurch City Council uses an intermediate set of values in which pedestrian flows > 60 ped/h, vehicles >1,000 veh/h, and the product >60,000.

AUSTRALIA

Chapter 4 of the 3rd Edition of the VicRoads (State of Victoria Transportation Department in Australia) *Traffic Engineering Manual* (*96*) provides the following pedestrian crossing guidelines (this chapter should be read in conjunction with AUSTROADS Guide to Traffic Engineering Practice, 1995, Part 13 - Pedestrians):

Major Traffic Control Items

The following pedestrian facilities are major traffic control items (MTCI) and may only be installed, removed, or altered with written approval from VicRoads:

- Pedestrian crossing signs, and
- Traffic signals.

This means that pedestrian crossings (with or without flashing lights) and pedestrian operated signals (including those for school children and other pedestrians) such as Pelican crossings and Puffin crossings are covered by the requirements of the MTCI.

Minor Traffic Control Items

Other pedestrian devices are not MTCIs but also give improved safety and mobility to pedestrians. Pedestrian refuges are devices that provide protection for the pedestrian in the center of the road, enabling them to cross a single direction of traffic at a time. They can be used in conjunction with other devices where road width is sufficient. Traffic islands, medians, and safety zones are all forms of pedestrian refuges. A pedestrian overpass/underpass may be appropriate where two generators of pedestrian traffic are on opposite sides of a highway.

In addition to the more specific guidelines given in the remainder of Chapter 4 of the VicRoads *Traffic Engineering Manual* Volume 1, its table (shown below as Table F-9) will assist in the selection of the most appropriate pedestrian device, according to the classification of the road. Neither this table nor the more specific guidelines which follow should be taken as the sole criteria by which the need for a particular facility is assessed. Matters such as capacity, safety, and the level of service (LOS) for all road users must be considered.

The following sections outline the numerical guidelines for determining whether a particular pedestrian facility is appropriate. It must be noted that these are guidelines and the numerical values are not the only factors to consider for determining the need or appropriateness of a pedestrian device. Other factors requiring consideration include speed zones, pedestrian needs/desire lines, neighboring facilities, types of pedestrians, road geometry, accident history, abutting land use, proximity of alternative pedestrian devices, and other site-specific conditions.

TABLE F-9. Guidelines for the Selection of Appropriate Midblock Pedestrian Facilities According to Road Classification (*96*).

	Overpass or Underpass	Pedestrian Operated Signals	Pedestrian Crossing (with flashing lights)	Pedestrian Crossing (without flashing lights)	Flagged School Crossing	Pedestrian Refuge
Primary Major	†o	•	x	x	o+	o
Secondary Major	o	•	o	x	o	o
Collector	x	o	o	o	•	•
Local	*	*	o=	o=	o	o

- • Most likely to be appropriate
- o May be an appropriate element
- x Inappropriate element
- * Pedestrian devices should not be needed
- + Flagged school crossings are sometimes used on low volume primary majors especially in rural areas
- = Pedestrian crossings (zebra crossings) may be appropriate in a local shopping centre
- † If the primary major is a freeway, an overpass or underpass must be used

Pedestrian Crossings without Flashing Lights

It is acceptable to install pedestrian crossings without twin diagonal flashing lights. However, these devices should only be used under certain circumstances, which are indicated in the guidelines shown in Table F-10.

TABLE F-10. Guidelines for the Installation of Pedestrian Crossings without Flashing Lights.

- **Acceptable locations for Pedestrian Crossings without flashing lights:**
  - Collector and local roads on which traffic speeds are low,
  - Left-turn slip or turn lanes at signalized intersections where VicRoads Regions consider these lanes to be necessary,
  - Car parks or parking lots,
  - Other off-road situations, e.g., caravan parks, reserves,
  - Where a children's crossing is justified and a significant number of pedestrians cross at other (non-school) times of the day,
  - Service roads where pedestrian operated signals or intersection signals operate on the main carriageway or highway, and
  - Across major roads.
- **Unacceptable locations:**
  - Left- turn slip or turn lanes at unsignalized intersections (unless considered necessary for pedestrian safety), and
  - Where there is poor visibility on the approach to the proposed site of the crossing, or where conspicuity of the device may be less than optimal.
- **General Guidelines:**
  - Pedestrian volumes of 20 or more per hour,
  - Vehicle volumes of 200 or more per hour for the same hour, and
- Maximum speeds of 37 mph (60 km/h) (85^{th} percentile).

- **Pedestrian Operated Signals.** Pedestrian operated signals may be provided where the following guidelines are met (for any hour on an average weekday):
  - The number of pedestrians (P) crossing within 65.5 ft (20 m) of proposed site exceeds 100, ***and***
  - The number of vehicles (V) which pedestrians have to cross exceeds 500 on an undivided road or 1,000 where there is a median or refuge, ***or***
  - A pedestrian crossing (zebra) would normally be justified but the operation of the crossing would interfere with the progression of vehicles to and/or from a nearby traffic signal installation and it would be practicable for the operation of pedestrian operated signals at or near the proposed site to be coordinated with the nearby signals, ***or***
  - A pedestrian crossing (zebra) would normally be justified but would be hazardous for pedestrians due to conditions at the site (e.g., disabled or elderly pedestrians, high vehicle approach speeds, high traffic volume, poor visibility, etc.), ***or***
- Where accident records indicate that two or more pedestrian casualty accidents have occurred in the last 3 years.

TABLE F-10. Guidelines for the Installation of Pedestrian Crossings without Flashing Lights (continued).

- **Appropriate locations for Pelican Crossings**
  - Where the posted speed limit is 31 mph (50 km/h) or less and vehicle operating speeds are generally 40 mph (65 km/h) or less, ***and***
  - Where pedestrian operated signals are installed and the pedestrians often cross the road so quickly, or in such small numbers, that delays to traffic after the last person has crossed are excessive, ***and***
  - Where it is important to minimize the delays to traffic flow caused by pedestrians crossing a major road, ***and***
  - The site has public lighting to AS (Australia Standard)/NZS (New Zealand Standard) 1158 standard or to AS/NZS 1158 standard – flood lighting at pedestrian crossings, ***and***

At locations with medians, there is good sight distance across the median.

- **Appropriate Locations for Puffin Crossings**
  - Wherever normal pedestrian operated signals are installed or warranted, ***and***
  - Where there is a known daily significant usage by slower moving (i.e., disabled or elderly) pedestrians, ***or***
  - Where large numbers of pedestrians cross the road during certain periods of the day, ***and***
  - Where it is important to minimize the delays to traffic flow caused by pedestrians crossing a major road.

  - Note: Descriptions of zebra crossings, Pelicans, Puffins, and Toucan crossings are described in the ITE Informational Report entitled "Alternative Treatments for At-Grade Pedestrian Crossings *(44)*."

SUMMARY

Following is a brief review of each set of guidelines:

United States: The information summarized in this contains very specific guidelines based on research (*31*) relating to the placement of marked crosswalks at uncontrolled locations on various types of streets. This information could be used to develop warrants for the *MUTCD*.

Canada: The Transportation Association of Canada has established guidelines (*93*) for the placement of pedestrian crossings that are both signalized and unsignalized. The province of Ontario has its own set of warrants. These guidelines and warrants could also be utilized to develop warrants for the *MUTCD*.

United Kingdom: The U.K.'s guidelines for assessing pedestrian crossing (*95*) facilities requires the user to take into account a variety of factors for installing pedestrian crossings but does not provide specific warrants, criteria, or benchmarks. The staff at DLTR (Department of Local Government Transport and the Regions) indicated on the European Scanning Tour (***97***) that they have specifically avoided using numerical values in their guidelines, and they want the guideline users to employ engineering judgment in the final decision on whether to install a particular type of crossing.

Australia: Very specific guidance is provided in the VicRoads (*96*) traffic manual about the placement of various types of pedestrian crossing facilities. These standards are rigidly applied and seldom ignored. They are quite detailed and would not readily be applicable to the practice in the United States because Pelican and Puffin midblock signals are not used. However, if the research indicates that these types of midblock signals would be beneficial, the VicRoads manual would provide a good starting point for developing warrants in the *MUTCD*.

Local agencies in the United States: The guidelines developed by the cities of San Luis Obispo and Sacramento in California contain specific guidance on the use of various types of midblock unsignalized crossings. These could be used to develop warrants in the *MUTCD* specifically relating to these types of facilities.

PEDESTRIAN CROSSING INSTALLATION CRITERIA

A summary of criteria identified during this TCRP/NCHRP project for pedestrian crossing installation criteria is summarized in the following tables. Table F-11 lists the criteria for signals, Table F-12 lists the criteria for marked crosswalks, and Table F-13 lists the criteria for other types of treatments.

TABLE F-11. Summary of Pedestrian Treatment Guidelines – Signals.

Source (Treatment)			
Volume		**Distance to next crossing/signal**	**Reductions allowed or Miscellaneous**
Pedestrian	**Vehicle**		
***MUTCD* (Signal)**			
100 ped/h for 4 hr or 190 ped/h for 1 hr	Fewer than 60 gaps/hr	>300 ft (91.4 m) (unless will not restrict progression)	50 percent if crossing speed is <4 ft/s (1.2 m/s)
Redmond, Washington, 5/5/03 Crosswalk Marking Practice (Midblock Signal)			
80 ped/h for 4 hr or 152 ped/h for 1 hr	Fewer than 60 gaps/hr	>300 ft (91.4 m) (unless will not restrict progression)	• 50 percent if crossing speed is <4 ft/s (1.2 m/s) • Redmond City Council approved the reduction of the pedestrian signal warrant volumes to 80 percent of *MUTCD* requirements on 7/2/02
Sacramento, California, Jan 2003 (Pedestrian signal or bridge)			
	2 lane: 15,000 vpd/40 mph (64.4 km/h) posted speed 3 lane: 15,000 vpd/35 mph (56.3 km/h) or 12,000 vpd/40 mph (64.4 km/h) 4+ w/median: 15,000 vpd/30 mph (48.3 km/h), 9,000 vpd/40 mph (64.4 km/h) 4+: 15,000 vpd/30 mph (48.3 km/h), 12,000 vpd/40 mph (64.4 km/h)		
Los Angeles (Traffic Signal – Intersection)			
100 ped/h for any 4 hr or 190 ped/h for 1 hr	Less than 60 gaps/hr	300 ft (91.4 m)	New signal will not seriously disrupt progression
Canada, 1998 (Pedestrian Signal)			
When crossing opportunities/hour are 60 or less and EAU (ped/h) = 50 (<10,000 pop), 55 (10,000 to 250,000 pop) or 60 (>250,000 pop)			• Consider accident history • Pedestrian volume converted into equivalent adult units – EAU (children 2X, seniors 1.5X, disabled 2X, adults 1X) • Smaller communities allow reduction to EAU (-10 for <10,000, -5 for 10,000 to 250,000, and no adjustment for >250,000) • Provides graphs that converts traffic volume to crossing opportunities for different traffic patterns
Seattle, Washington (Half-Signal –Warrant A)			
			Graph includes consideration of main street volume, pedestrian volumes, walking speed of 3.5 ft/s (1.1 m/s), and accepted gaps

TABLE F-11. Summary of Pedestrian Treatment Guidelines – Signals (continued).

Source (Treatment)			
Volume		**Distance to next crossing/signal**	**Reductions allowed or Miscellaneous**
Pedestrian	**Vehicle**		
Seattle, Washington (Half-Signal –Warrant B)			
Pedestrian generator is present	500 veh/h for 8 hr 30 usable gaps across main street in 30-min period (formula provided)	300 ft (91.4 m) between proposed signal and nearest existing signal (except on one-way street)	If 85th > 40 mph (64.4 km/h), the main street volume can be reduced to 400 veh/h (80 percent of original)
Seattle, Washington (Half-Signal – Disabled or Senior Citizen)			
Four lane, 30 mph (48.3 km/h) or less speed limit: 100 disabled or senior citizen during 8-hr period and during highest pedestrian volume hour must be fewer than 60 adequate gaps Two lane, 30 mph (48.3 km/h) or less speed limit: 200 disabled or senior citizen during 8-hr period and during highest pedestrian volume hour must be fewer than 60 adequate gaps			• For streets with > 30 mph (48.3 km/h) speed limits, the required disabled or senior citizen pedestrian volume shall be reduced to 80 percent of the requirement • Pedestrian volumes may be increased if information indicates that an immediate increase in actual volume can be anticipated
Los Angeles, California (Traffic Signal – Midblock)			
Pedestrian volume guidelines of Manual of Policies and Procedures Section 344 (see marked crosswalk, uncontrolled) is satisfied		300 ft (91.4 m) (street to be crossed is at least 50 ft [15.2 m] wide)	Used for the purpose of consolidating midblock crossings to a single, preferred point
Traffic Control Devices Handbook (HAWK, flashing warning beacon, in-roadway lights and signs)			
Approximately ½ of pedestrian signal warrant volumes Meets guidelines for marked crosswalk		No other crossing controlled by signal or stop sign within 600 ft (182.9 m)	

TABLE F-12. Summary of Pedestrian Treatment Guidelines – Marked Crosswalk.

Source (Treatment)			
Volume		**Distance to next crossing/signal**	**Reductions allowed or Miscellaneous**
Ped	**Vehicle**		
2002 FHWA UNC report (Marked Crosswalks)			
Min 20 ped/peak hour (15 or more older or child)	Ranges of <9,000, 9,000 to 12,000, 12,000 to 15,000, and >15,000 vpd		Provided recommendations (Candidate, Possible Increase in Crashes, and Insufficient) based on number of lanes, speed limit, and vehicle ADT
ITE RP Design and Safety of Pedestrian Facilities (Marked Crosswalk)			
Graph of ADT and hourly pedestrian volume by number of lanes		600 ft (182.9 m)	
Arizona (Marked Midblock Crosswalk)			
High pedestrian volume generator and "reasonable demand" (no values provided)		1000 ft (304.8 m) between intersections and 400 ft (121.9 m) from nearest intersection	Point system (max 33) that considers: • Average gaps/5 min (10 pts for <1 to 0 pts for 5 or more gaps/5 min) • Pedestrian volume during hour of max veh-pedestrian conflicts (10 pts for >100 crossings and 0 pts for <10 crossings) • Veh speed (5 pts for 29 to 37 mph [46.7 to 59.5 km/h], 3 pts for 20 to 28 mph [32.2 to 45 km/h], 1 pt for 38 to 45 [61.2 to 72.4 km/h] or under 20 mph [32.2 km/h], and no marked crossings should be installed on roads with posted speed > 45 mph [72.4 km/h]) • General conditions, max 8 pts (2 pts each for: clarify pedestrian routes, channelize pedestrian into shorter path, position pedestrian to be seen, position pedestrian to expose to few vehicles)
Redmond, Washington 5/5/03 Crosswalk Marking Practice (Marked Crosswalks)			
20 ped/peak hour (or 15 or more older or child ped) – high priority on the installation			At all-way stop-controlled intersections and signalized intersections
Redmond, Washington 5/5/03 Crosswalk Marking Practice (Marked Crosswalk, Unsignalized Intersection)			
20 ped/peak hour (or 15 or more older or child ped) – high priority on the installation	Matrix from the 2002 FHWA study (also known as UNC study)	600 ft (182.9 m)	Additional factors to be considered: stopping sight distance (SSD), illumination, geometrics, heavy trucks, attention demands, risk factors
San Luis Obispo (Marked crosswalks – Intersection)			
40 ped/h for peak hour 30 groupings of 2 or more pedestrian for a continuous 2-hr period twice a day	2700 ADT or more for residential street	Minimum of 600 ft (182.9 m) to nearest controlled crossing	• 85^{th} percentile speed is below 40 mph (64.4 km/h) • Less than three travel lanes in one direction • Minimum sight distance available

TABLE F-12. Summary of Pedestrian Treatment Guidelines – Marked Crosswalk (continued).

Volume		Source (Treatment) Distance to next crossing/signal	Reductions allowed or Miscellaneous
Ped	**Vehicle**		
San Luis Obispo, California (Marked Crosswalk – Midblock)			
High pedestrian volume generator nearby		Distance between intersection is 660 ft (201.2 m)	
Reasonable demand		Reasonable demand to cross within a concentrated area that is 200 ft (61 m) from nearest controlled intersection	
Sacramento, California, Jan 2003 (Various : triple-four, pedestrian refuge, overhead flashing beacons, Level 1, Level 2, pedestrian signal, pedestrian bridge)			
	Yes		• Recommendations provided by numbers of cars, posted speed, and number of lanes (2, 3, 4, 5 lanes)
Canada (Special Crosswalk) When crossing opportunities/hour are 90 or less and EAU (ped/h) = 30 (<10,000 pop), 35 (10,000 to 250,000 pop) or 40 (>250,000 pop)			• Consider accident history • Pedestrian volume converted into equivalent adult units – EAU (children 2X, seniors 1.5X, disabled 2X, adults 1X)
Canada (Signed and marked crosswalk) When crossing opportunities/hour are 120 or less and EAU (ped/h) = 10 (<10,000 pop), 15 (10,000 to 250,000 pop) or 20 (>250,000 pop)			• Smaller communities allow reduction to EAU (-10 for <10,000, -5 for 10,000 to 250,000, and no adjustment for >250,000) • Provides graphs that converts traffic volume to crossing opportunities for different traffic patterns
New Zealand (Pedestrian crossing) Product of number of pedestrian and vehicles exceed 45,000 and Number of vehicles is not less than 300			
AUSTROADS (Pedestrian crossing) 60 ped/h, 600 veh/h, and product of ped and veh > 90,000			
Seattle, Washington (Marked crosswalk)			
	Matrix from 2002 FHWA study	200 ft (61 m) (to nearest existing signal (with some exceptions)	• Include engineering evaluation that considers other factors (e.g., pedestrian volumes, etc.)

TABLE F-12. Summary of Pedestrian Treatment Guidelines – Marked Crosswalk (continued).

Volume		Source (Treatment) Distance to next crossing/signal	Reductions allowed or Miscellaneous
Ped	Vehicle		
Los Angeles, California (Marked Crosswalk: uncontrolled – MPP 344)			
20 pedestrian units/hr (minimum)		300 ft (91.4 m) to nearest controlled or marked crossing (minimum)	• 85^{th} percentile speed does not exceed 45 mph (75.2 km/h) (or posted does not exceed 40 mph [64.4 km/h]), minimum • Must satisfy all minimums and one of the following three guidelines: o Pedestrian volume: 40 or more/hr during peak hour or 30 or more/hr during each of any 2 hr (children under 13, older over 64, and disabled counts as 2 ped) o Pedestrian route definition o Special facility (e.g., transit stop, school crossing, etc.) • Pedestrian crashes: 2 during 12 months or 3 during 2 years of most recent 4 years, consider prohibition of crossing, signal, smart ped warning, or marked crosswalk
Eugene, Oregon, Design Standards, Nov 99 (Midblock crossing)			
25 ped/h for peak 4 hr with ADT >10,000 and speeds are 40 mph (64.4 km/h) or less		Intersection crossings are spaced greater than 600 ft (182.9 m), or so that crosswalks are located more than 400 ft (121.9 m) (apart in high pedestrian volume locations	• Reduce pedestrians to 10 ped/h (peak 4 hr) when significant numbers of children, elderly, or disabled are present • Consider curb extensions and/or raised median islands
Florida, Pedestrian Planning & Design Handbook (Marked Crosswalk)			
• Included the curves developed by Smith and Knoblauch • High numbers of ped crossings (>25 ped/h)	At channelized islands: number of ped X num of veh exceeds 800/hr	Can concentrate or channelize multiple ped crossings to single location	

TABLE F-13. Summary of Pedestrian Treatment Guidelines – Other Treatment Types.

Volume		**Distance to next crossing/signal**	**Miscellaneous**
Ped	**Vehicle**		
Redmond, Washington, 5/5/03 Crosswalk Marking Practice (In-pavement lighting system)			
100 ped/day (considering a revision to 40 ped/h for 2 hr)	Average weekday daily traffic volume between 5,000 and 30,000 veh/day	Over 250 ft (76.2 m) to nearest crosswalk or traffic control device (considering revised value of 300 ft [91.4 m] and adding statement about considering location and traffic volume of driveways impacting the crosswalk)	• Max of two travel lanes to cross (considering a revision to no more than three lanes or four lanes with a raised pedestrian refuge median) • 85th percentile speed of 45 mph (72.4 km/h) or less • SD = 400 ft (121.9 m) (< 35 mph [56.3 km/h]) or 600 ft (182.9 m) (35 to 45 mph [56.3 to 75.2 km/h])
***MUTCD* (In-pavement lighting system)**			
			• Marked crosswalk • Not at a stop, yield, or signal-controlled location
San Luis Obispo, California (In-road pavement lighting)			
100 veh/h for any 4 hr, or 100 groups of 2 or more pedestrians for a continuous 2-hr period twice a day	10,000 veh/day		• 85th percentile speed is 35 mph (56.3 km/h) or less • Two or more travel lanes in one direction but not more than four through lanes in both direction • Not controlled by signal, stop, or yield sign • AFTER DARK: ped volume is 75 ped/h for 1 hr or 25 ped/h for any 4 hr during nighttime
Sacramento, California, Jan 2003 (Various : triple-four, ped refuge, overhead flashing beacons, Level 1, Level 2, ped signal, ped bridge			
	Yes		• Recommendations provided by numbers of cars, posted speed, and number of lanes (2, 3, 4, 5 lanes)
Canada (Post-mounted signs and markings, overhead signs and markings, special crosswalk, ped signal)			
Ped volume converted into equivalent adult units – EAU (children 2X, seniors 1.5X, disabled 2X, adults 1X)	Crossing opportunities in 1 hr		• Consider accident history • Smaller communities allow reduction to EAU (-10 for <10,000, -5 for 10,000 to 250,000, and no adjustment for >250,000)

TABLE F-13. Summary of Pedestrian Treatment Guidelines – Other Treatment Types (continued).

Volume		Source (Treatment) Distance to next crossing/signal	Miscellaneous
Ped	**Vehicle**		
Los Angeles, California (Smart Pedestrian Warning)			
	10,000 veh/day	300 ft (91.4 m) of a controlled crossing, 200 ft (61 m) of a railroad crossing, or 300 ft (91.4 m) of any other flashing yellow warning beacon Roadway to be crossed is 50 ft (15.2 m) or more	• Point system o Ped volume – up to 8 pts for 136 ped/h peak hour, 91 or more for 2 hr, 51 or more for each of any 4 hr. Note that <13 yr old children, 64+ year old seniors, and disabled persons count as 2 ped units o Veh volume – up to 8 pts for >2001 veh/h total of both directions o Speed – up to 6 pts for 40.1 mph (64.5 km/h) or faster 85th percentile speed o Up to 6 pts for 7 lanes or more o Up to 10 pts for crashes o Up to 4 pts for special facilities o Up to 4 pts for restricted visibility
Florida Traffic Engineering Manual Feb 03 (In-roadway lights)			
References *MUTCD*			• Only at marked midblock crosswalks with ped heads • Not on: four lanes, posted speed above 45 mph (72.4 km/h), where yield, stop, or signal control present

APPENDIX G

INTERNATIONAL SIGNAL WARRANTING PRACTICES

This Appendix summarizes a sample of international practices related to pedestrian signal warranting criteria. It was based on international practices as identified through literature searches and world wide web searches.

In the United States, the *Manual on Uniform Traffic Control Devices* (*MUTCD*) governs the applications of traffic control devices for all 50 states. While supplements can be developed to address local or regional concerns, there is little deviance from the national *MUTCD*. Therefore, the purpose of this Appendix is to provide a flavor of various warranting criteria that international transportation agencies use to consider the need for a traffic signal based on pedestrians.

Table G-1 compares the U.S. pedestrian warranting considerations to those international pedestrian warranting considerations that have been reviewed.

TABLE G-1. Pedestrian Warranting Factors.

Warranting Factors	USA	United Kingdom	Canada	Australia	South Africa
Pedestrian Volume	✓	✓	✓	✓	✓
Vehicle Gap Availability	✓		✓		
Vehicle Speed		✓	✓		✓
Nearest Traffic Signal	✓	✓	✓	✓	
Vehicle Progression	✓		✓	✓	
Nearest Crosswalk				✓	
Adjacent Land Use		✓			
Crash Experience		✓	✓	✓	
Roadway Cross Section		✓			✓
Roadway Class		✓			
Walking Speed	✓	✓			
Peak Hour Delay		✓			
Pedestrian Composition	✓	✓		✓	✓
Vehicle Delay		✓	✓	✓	
Vehicle Volume		✓	✓	✓	✓
Latent Demand (Vehicle)			✓		

UNITED KINGDOM (*98*, *99*, *100*)

Official guidance on whether a pedestrian crossing should be provided and, if so, what sort of crossing is most suitable, is contained in Local Transport Note (LTN) 1/95 and LTN 2/95. These documents recommend use of an assessment framework. The site should be surveyed approximately 164 ft (50 m) either side of the proposed crossing point and all relevant information recorded, including:

- Carriageway and footway type and width,
- Surroundings,
- Vehicular/pedestrian flow and composition,
- Average crossing time and difficulty of crossing, and
- Road accidents.

The crossing options should then be assessed against the relevant factors which are likely to include:

- Difficulty in crossing,
- Peak hour vehicle delay,
- Carriageway capacity,
- Vehicle speeds,
- Local representations, and
- Cost.

LTN 1/95 introduced a more comprehensive and flexible assessment procedure than was previously required. It replaces the PV_2 criterion where P = pedestrian flow and V = vehicle flow: the general rule was that a Pelican crossing should only be installed if $PV_2 > 1 \times 10^8$ (although other factors, such as proximity to a school or hospital, could be taken into account if the PV_2 criterion was not met). Although now officially superseded, PV_2 remains in day-to-day use and comparison of the methods is interesting.

The planning, design, and installation of pedestrian crossings are prescribed in LTN 2/95. This covers all types of at-grade crossings, including pedestrian refuges, zebra crossings, and various types of signal-controlled crossings. Advice is given in relation to the proximity of junctions, school crossing patrols, visibility, crossing width, guard railing, crossing approach, surfaces, disabled pedestrians, lighting, signing, bus stops, and street furniture. Under the Road Traffic Regulation Act of 1984, it is no longer necessary for local highway authorities to obtain approval from the government for installation or removal of a pedestrian crossing. However, they should consult locally and inform the Department of the Environment, Transport, and the Regions (DETR).

CANADA (*101*)

The Canadian *MUTCD* is generally very similar to the U.S. *MUTCD*. However, at least one significant difference is in the way in which traffic signal warranting criteria are established and used. The following pages show how the Canadian *MUTCD* addresses traffic signal warrants (pedestrian consideration is integrated into the overall process). The process is much more involved than in the United States and is more akin to the *Highway Capacity Manual* (*HCM*) procedures.

B2 INSTALLATION GUIDELINES FOR TRAFFIC CONTROL SIGNALS

The description of installation guidelines for traffic control signals and their application is organized as follows:

Section B2.1 General considerations
Section B2.2 The use of warrants

B2.1 GENERAL CONSIDERATIONS FOR INSTALLATION OF TRAFFIC CONTROL SIGNALS

Prior to the installation of traffic control signals, consideration should be given to other control measures, and an analysis should confirm that traffic signal control would be more effective in attaining the desired operational objective.

The analysis should consider the following factors, which are described further below:

(a) Safety considerations
(b) Operational considerations
(c) Physical suitability
(d) Strategic considerations
(e) Special considerations

It is important to recognize that traffic signal control will not operate effectively in isolation of other traffic control devices such as signs and pavement markings. All traffic controls operate as complementary elements that address common objectives.

The operation of a traffic control signal consists of a program of phase types, phase sequences and phase timings. A traffic signal may respond to changing demand through the presence of vehicle detectors or pedestrian pushbuttons, or through a predefined response based on historical demand fluctuations.

B2.1.1 Safety Considerations

A desire to improve traffic safety may be one reason for the installation of a traffic control signal. However, it must be emphasized that a signal installation will not guarantee improved traffic safety. Traffic signal control may be recommended on the basis of safety if some of the following conditions exist:

(a) abnormal number of right-of-way violations;
(b) insufficient sight distance;
(c) operating conditions which promote acceptance of unsafe gaps;
(d) abnormal left-turn hazard;
(e) abnormal pedestrian hazard; or
(f) protection requirements for special population groups (children, senior citizens or the disabled) which cannot be provided in other ways.

SEPTEMBER 1998

B2.1.2 Operational Considerations

The management of delay for both pedestrians and drivers is another reason for the utilization of traffic signals. Traffic signal control, in conjunction with appropriate geometric design and pavement markings, can minimize delay and queuing. The operational characteristics that lead to a requirement for traffic signals include:

(a) a continuous queue of through and left-turning vehicles on one or more approaches at times of peak demand; or

(b) abnormal delays to through and left-turning vehicles.

Before adopting traffic signal control as a response strategy to the observed conditions, the following must be considered:

(i) Could operational improvements be accomplished by reorganizing traffic flow (i.e. left-turn lanes; channelized right turns; turn prohibitions)?

(ii) Could a less restrictive form of intersection control be implemented with success (i.e. Stop sign control to replace Yield sign control; multi-way Stop sign control sign to replace two-way Stop signs)?

(iii) Is it possible to implement traffic signal control without seriously affecting adjacent intersections and nearby roads?

(iv) Is sufficient intersection capacity available to implement traffic signal control?

(v) Will left turns impede through traffic if traffic signal control is implemented?

(vi) Are left-turn lanes available? Will they be required?

(vii) Will the installation of the traffic control signals promote the use of less desirable routes?

(viii) Will the installation negatively affect safety?

B2.1.3 Physical Suitability

The physical characteristics of the intersection and its approaches must be evaluated to determine whether a traffic control signal may be operated safely and effectively. Examples of factors which may make traffic signal control difficult

(a) Steep grades on one approach leg could make stopping or starting of vehicles difficult or impractical, especially during adverse road and weather conditions;

(b) A severely skewed angle of intersection could result in excessively long vehicle and pedestrian clearance phases, and a very inefficient signal operation;

(c) Offset intersection legs could result in excessively long vehicle and pedestrian clearance intervals and undue conflict between vehicles and pedestrians; or

(d) Horizontal or vertical alignments could reduce signal visibility.

B2.1.4 Strategic Considerations

Traffic signal control has effects beyond the immediate controlled intersection. Therefore, the following must be considered when such control is contemplated:

(a) coordination with adjacent signalized intersections;

(b) uniformity of operation of traffic control signals;

(c) capacity of the subject intersection relative to upstream and downstream intersections;

(d) potential for adjacent network disruption or over-saturation;

(e) effect on adjacent land uses; and

(f) effect on neighbourhoods.

B2.1.5 Special Considerations (Transit, Police, Fire, Waterways, Railways)

Situations may arise which require preferential traffic control, at regular or intermittent intervals, for public transit, emergency response, opening bridges at waterways, or railway control integration purposes. The following must be considered when traffic control signals are used in such circumstances:

(a) overall vehicular and pedestrian safety;

(b) the benefit to the special user; and

When traffic control signals are operated in close proximity to a railway grade crossing, care should be taken to ensure that the operation of the traffic control signal does not cause blockage of the railway tracks. Furthermore, visual conflict between the traffic signal indications and the railway crossing protection equipment must be avoided.

In order to meet these objectives, it must be determined if a traffic control signal will cause vehicular queues to extend to the railway crossing during normal operating conditions. It will normally be desirable to interconnect the two control devices such that operation of the traffic control signal may be pre-empted by the track circuits and automatic crossing protection equipment. In such cases, authority must be obtained from the Canadian Transportation Agency, the railway operator, as well as local and provincial agencies where required.

B2.2 The Use of Warrants

Traffic control signals may be used anywhere conflicting traffic movements exist. Therefore, it is necessary to ensure that the application of this form of control is carried out in a consistent manner. This will also provide assurance that these devices will meet anticipated control objectives.

A method which can assist in this regard is a warrant system. Such a system provides a simplified analysis incorporating characteristics such as geometry, pedestrian and vehicular volumes and collision history. The process yields a result which can be used as a priority indicator or installation justification indicator. The following warrant system is recommended for those wishing to make use of such a system. The user is cautioned that a warrant calculation alone is generally not sufficient background for making a decision on the installation of traffic control signals.

The warrant system involves the following:

(a) determination of whether the installation warrant is satisfied based on the total priority points (Subsection B2.2.1);

(b) completion of the traffic signal installation warrant and priority rating work sheet to calculate the total priority points (Subsection B2.2.2); and

(c) calculation of priority points related to collisions (Subsection B2.2.3), priority points for crossing gaps, signal progression, delay and vehicular stops (Subsection B2.2.4) and priority points for crossing gaps, intersecting volumes and pedestrian volumes (Subsection B2.2.5).

B2.2.1 Satisfaction of Installation Warrant

The installation of traffic control signals at a study intersection is warranted when the total priority points calculated by completing Figure B2-6 equal or exceed 100. The relative need or priority for traffic control signal installations at a number of possible locations is indicated by the relative number of total priority points.

The installation warrant and priority rating system provides a realistic technical analysis of the net effect of the installation of a traffic control signal at a specific location. It must be recognized, however, that it is only a guide, and does not remove the need for experienced and objective analysis.

At intersections which satisfy the installation warrant for only part of the year, such as those at summer recreation areas, consideration should be given to a semi-actuated control mode. Thus, even during very low volume conditions, motorists and pedestrians on the intersecting street will still receive the benefits of a clear indication of the right of way, while minimizing the effect on traffic on the through street.

B2.2.2 Traffic Signal Installation Warrant and Priority Rating Work Sheet

The work sheet shown in Figure B2-6 is used to calculate the total priority points for the intersection. The basic data requirements for the work sheet are described in Subsections B2.2.3 to B2.2.5. Part I should be completed and followed by insertion of the appropriate equations for each leg of the intersection in Parts IIA and/or Part IIB, and either Part IIIA or Part IIIB.

It should be noted that in Parts IIA and IIB, for four-leg intersections, only the four appropriate equations are calculated, and for three-leg intersections, only the three appropriate equations are calculated. For intersections having more than four legs, additional equations may be inserted. It will often be found, however, that such complex intersections should be simplified by the closure of one or more legs, since the operation of such intersections, with or without traffic control signals, is usually very inefficient.

B2.2.3 Priority Points for Collisions

Part I of the work sheet uses P_a (determined from Figure B2-1) which is an index assigned to express the relative effect which the operation of a traffic control signal would have on the collision rate at the location in question.

The information required to use Figure B2-1 is a representative figure for the number of reportable collisions per year prior to installation of traffic control signals.

B2.2.4 Priority Points for Crossing Gaps, Signal Progression, Delay and Vehicular Stops

Part II of the work sheet deals with crossing gaps, signal progression, delay and vehicular stops. The working terms used for Part II, including P_1, P_2, V_{tew}, V_{tns}, F_{eew} and F_{ens} are described below:

(a) P_1 for one-way streets is determined from Figure B2-2. It is a qualitative index which expresses individually, for each one-way leg of an intersection, the net effect which the operation of a traffic control signal would have upon:

- The availability of crossing gaps at the intersection, and at remote points from the study intersection;
- The progression of vehicles along the street, to or from other existing or proposed traffic control signals;
- The delay to vehicles on the street; and
- The number of stops to which vehicles are subjected by signal operation.

(b) P_2 for two-way streets is determined from Figure B2-3. It is a qualitative index which expresses individually, for each two-way leg of an intersection, the net effect which the operation of a traffic control signal would have upon the same four parameters as outlined for P_1 above.

(c) V_{tew} is the total annual average daily traffic volume on each individual leg of the east-west street, divided by 1000.

(d) V_{tns} is the total annual average daily traffic volume on each individual leg of the north-south street, divided by 1000.

(e) F_{eew} is an expansion factor to account for the increase in vehicular volume which would occur within one year on the east-west street of the study intersection, due to the installation of the traffic control signal.

(f) F_{ens} is an expansion factor to account for the increase in vehicular volume which would occur within one year on the north-south street of the study intersection, due to the installation of the traffic control signal.

The following data is required for each leg of the intersection, for use in Figure B2-2 or Figure B2-3, in order to determine indices P_1 and P_2:

- Distance to the nearest existing or proposed future traffic control signal;

- Likelihood that good progression between the nearest existing or proposed traffic control signal and the study intersection is attainable (for one-way streets only). In order to determine this factor, it is necessary to evaluate whether the offset of a traffic control signal at the study location would result in the stopping of vehicles which otherwise would flow unhindered through the intersection. In the case of a variable offset operation throughout the day, the offset which would accommodate the majority of daily vehicle movements should be used;

- Length of the system background cycle (for two-way streets only). The background cycle length which would be in operation for the period of the day during which the greatest total volume of vehicle movements would be accommodated should be used for this purpose. This is usually the "peak hour" cycle length. In cases where an isolated actuated traffic signal operation is proposed for the indefinite future, and there will be no other traffic control signals close enough to result in overlapping areas of influence, P_1 and P_2 should simply be assigned the maximum values of Figure B2-2 and Figure B2-3; and

- Desirable progression speed along the leg (for two-way streets only).

V_{tew} and V_{tns} are intended to be representative figures for the 24-hour volume of vehicular traffic using the study intersection during the part of the year the proposed traffic control signal would be operated. Normally, a traffic control signal would operate all year long, and the appropriate figure would be the annual average daily traffic. These figures are determined by modifying 24-hour counts by the use of day-of-the-week and month-of-the-year adjustment factors. If 24-hour counts are not available, they can be derived by expanding short-term counts. For this purpose, the short-term counts should be at least seven hours long, and should include both the morning and evening peak periods. The appropriate expansion factors should be determined from data derived from permanent counting stations at key locations. In areas having abnormal seasonal fluctuations, such as resort areas and their connecting roads, representative figures for the peak operating period should be used.

F_{eew} and F_{ens} are judgement factors for the purpose of reflecting the probable increase in vehicular volume on each street of the study intersection, due to an anticipated re-routing of vehicle drivers to use the newly signalized route. These factors may also be used to account for predictable increases in volume due to a projected road widening or new road connections. A catalogue of past experience should be compiled in order to improve judgement for future proposed traffic control signal installations. The following guidelines may be used to determine the factors F_{eew} and F_{ens}:

- Traffic volumes on the former "through" street will not usually increase except for normal growth, and the factor for the "through" street is usually close to 1.0;
- In cases in which the former "stop" street had no undue delay problems, or was the only alternative for drivers on the route, the factor for the "stop" street may range from 1.0 to 1.3; and
- In cases in which the former "stop" street drivers experienced appreciable delay, and other alternative routes suffered the same problems, the factor may range from 1.5 (low) to 2.0 (average) to 2.5 (high).

B2.2.5 Priority Points for Crossing Gaps, Intersecting Volumes and Pedestrian Volumes

Part III of the work sheet deals with crossing gaps, intersecting volumes and pedestrian volumes. The working terms used for Part III including V_{aew}, V_{ans}, P_{ew}, P_{ns}, F_r, F_l, F_{aw}, and P_3 are described below:

(a) V_{aew} is the total annual average daily traffic volume approaching the intersection on each individual leg of the east-west street, divided by 1000;

(b) V_{ans} is the total annual average daily traffic volume approaching the intersection on each individual leg of the north-south street, divided by 1000;

(c) P_{ew} is the total annual average daily pedestrian volume crossing the intersection in the east-west direction, divided by 1000;

(d) P_{ns} is the total annual average daily pedestrian volume crossing the intersection in the north-south direction, divided by 1000;

The annual average 24-hour figures for V_{aew}, V_{ans}, P_{ew} and P_{ns} are derived as described above for V_{tew} and V_{tns}.

(e) F_r (determined from Figure B2-4, for one-way streets only) is a qualitative factor representing the random arrival at the study intersection of a platoon of vehicles which has passed straight through the nearest upstream traffic control signal on a one-way street (NOTE: For signal spacing beyond 450 m, this factor becomes 1 and has no effect);

(f) F_r (determined from Figure B2-4, for one-way through streets only) is a qualitative factor representing the effect of secondary flows in reducing the length of the gaps otherwise available between platoons on a one-way street (NOTE: For signal spacing beyond 450 m, this factor becomes zero and has no effect);

(g) F_{ow} is a factor expressing the increased safety, capacity and facility of movement at the intersection of one-way streets, due to the smaller number of conflict points, as compared with two-way street intersections.

The value of F_{ow} is as follows:

- If both streets are two-way, $F_{ow} = 1.0$;
- If the through street is two-way and the cross-street is one-way, $F_{ow} = 0.9$;
- If the through street is one-way and the cross-street is two-way, $F_{ow} = 0.7$; and
- If both streets are one-way, $F_{ow} = 0.6$;

(h) P_3 (determined from Figure B2-5, for one-way through streets only) is a quantitative index which expresses the degree of difficulty experienced by vehicles and pedestrians crossing a through one-way street at the intersection under study. The difficulty in crossing the through one-way street is related to two principal factors:

- the extent to which the through-street gaps, created by the nearest upstream signal, are interrupted by traffic turning onto the through street; and

- the number of through-street pedestrians crossing the cross-street during gaps in through-street traffic.

The annual average 24-hour vehicle and pedestrian volumes for use on Figure B2-5 are derived as described above for V_{tew} and V_{tns}.

In order to determine the number of through-street pedestrians crossing the cross-street during through-street vehicle gaps, for use in Figure B2-5, it is assumed that pedestrian arrivals at the intersection are random. The number of pedestrians crossing the cross-street (P_{gx}) during the gaps in through street traffic is determined by using the following equation:

$$P_{gx} = \frac{P_{tt} \times T_x}{C_t}$$

P_{tt} is the total volume of through-street pedestrians crossing the cross-street.
T_x is the cross-street vehicle phase length at the upstream traffic control signal.
C_t is the cycle length at the upstream traffic control signal.

TRAFFIC SIGNALS
INSTALLATION GUIDELINES
B2

MANUAL OF UNIFORM TRAFFIC CONTROL DEVICES FOR CANADA

FIGURE B2-1

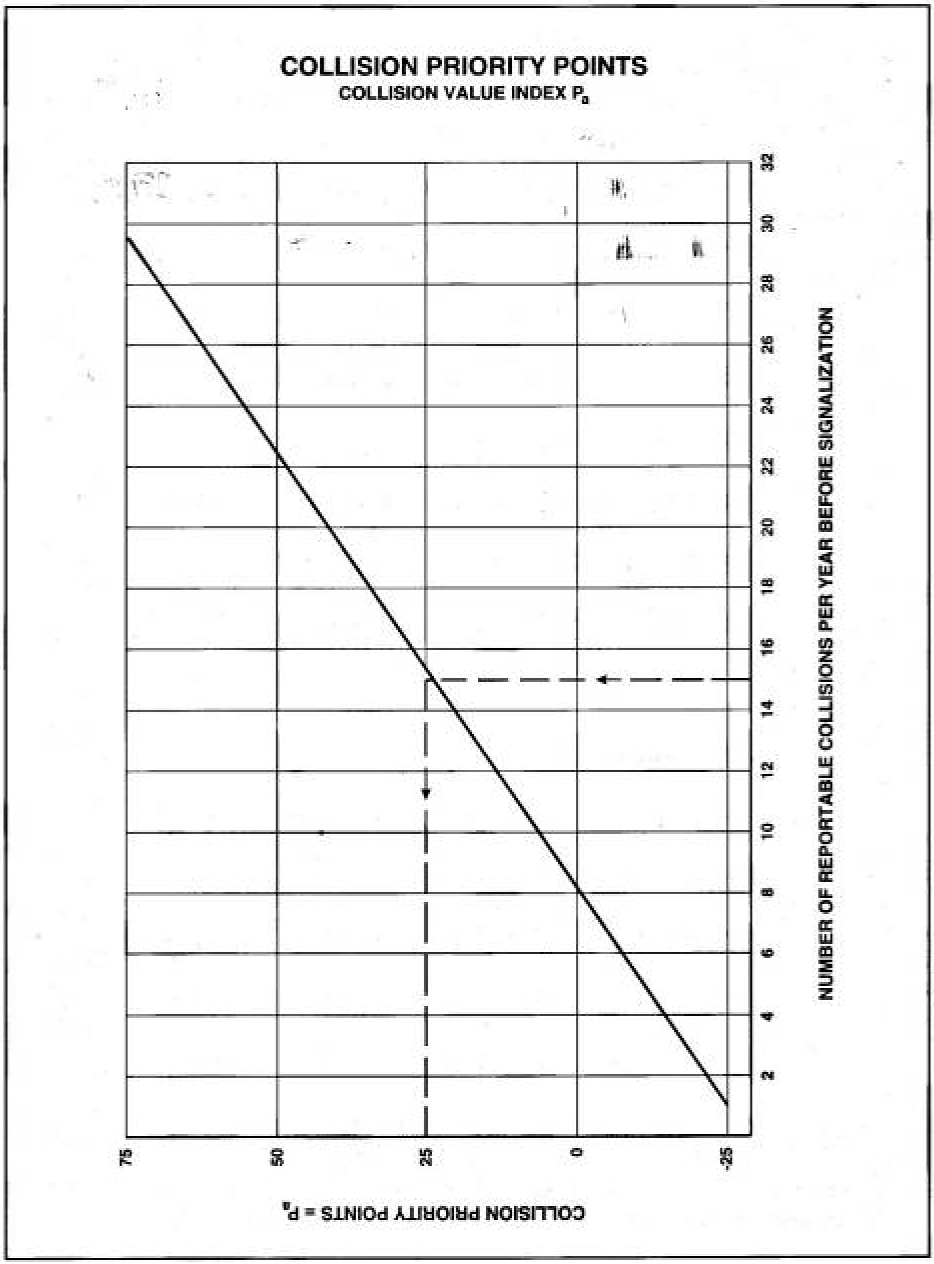


FIGURE B2-1

SEPTEMBER 1998

MANUAL OF UNIFORM TRAFFIC CONTROL DEVICES FOR CANADA

TRAFFIC SIGNALS
INSTALLATION GUIDELINES
B2

FIGURE B2-2

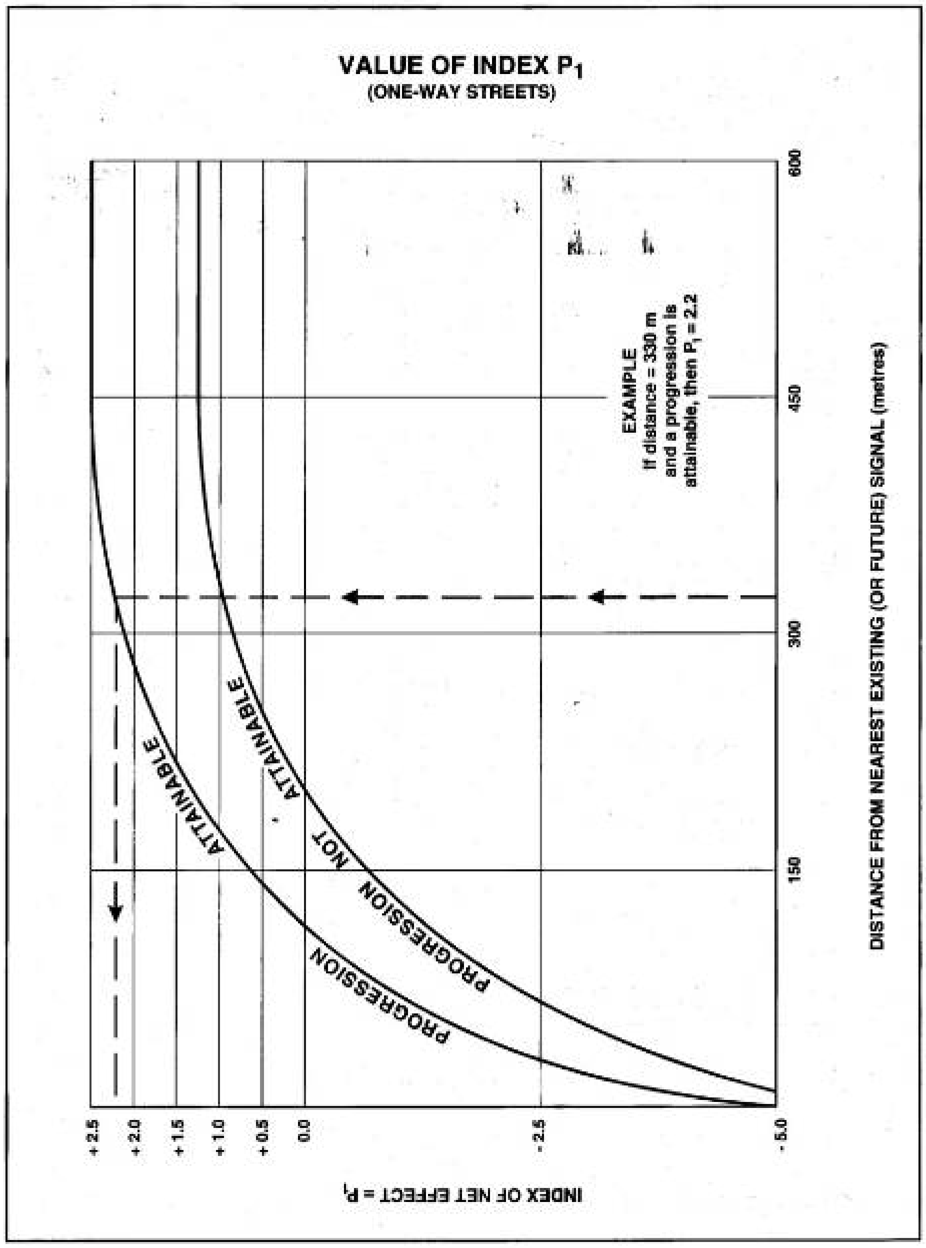


FIGURE B2-2

SEPTEMBER 1998

TRAFFIC SIGNALS

INSTALLATION GUIDELINES

B2

MANUAL OF UNIFORM TRAFFIC CONTROL DEVICES FOR CANADA

FIGURE B2-3

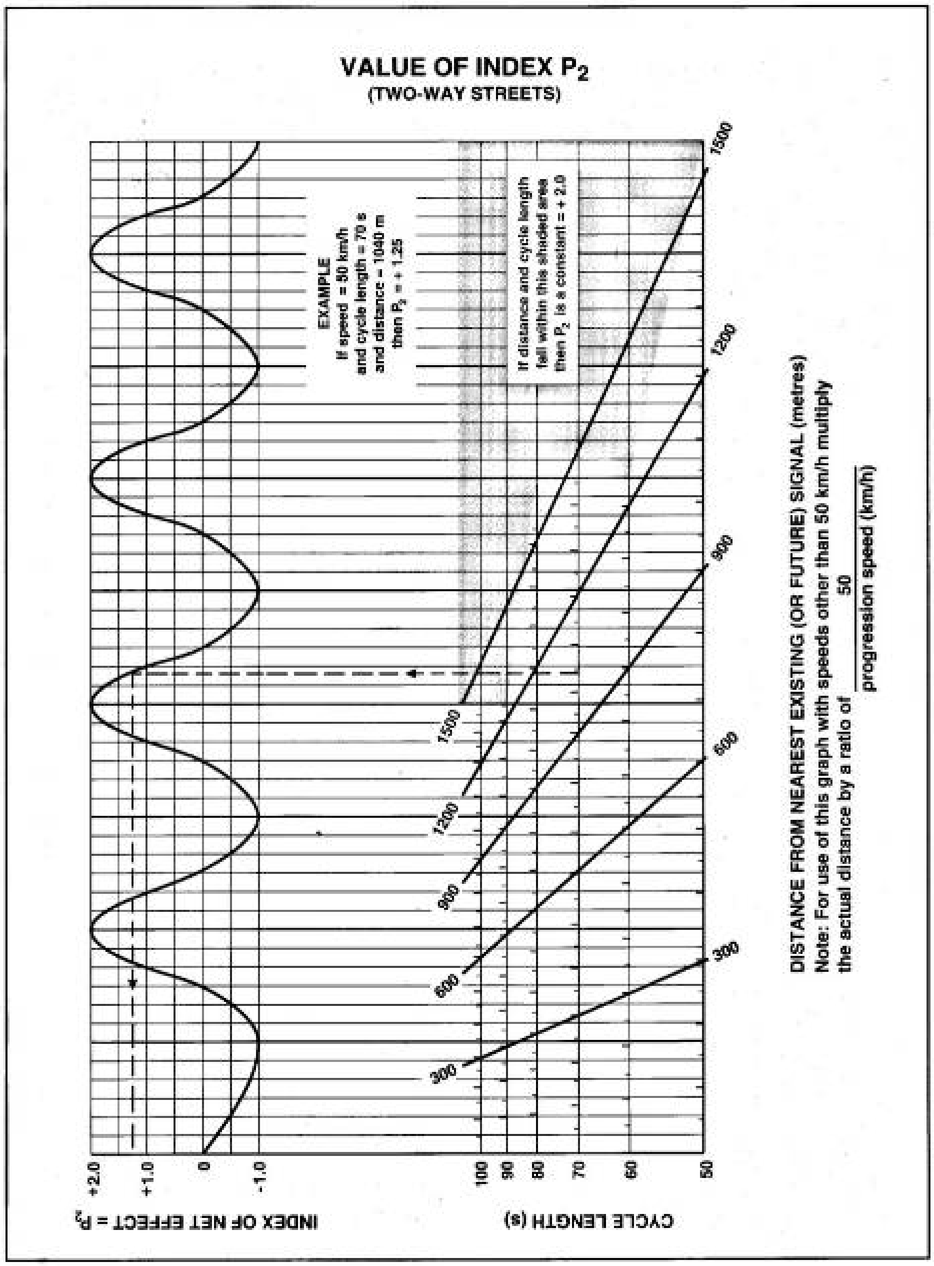


FIGURE B2-3

SEPTEMBER 1998

MANUAL OF UNIFORM TRAFFIC CONTROL DEVICES FOR CANADA

TRAFFIC SIGNALS
INSTALLATION GUIDELINES
B2

FIGURE B2-4

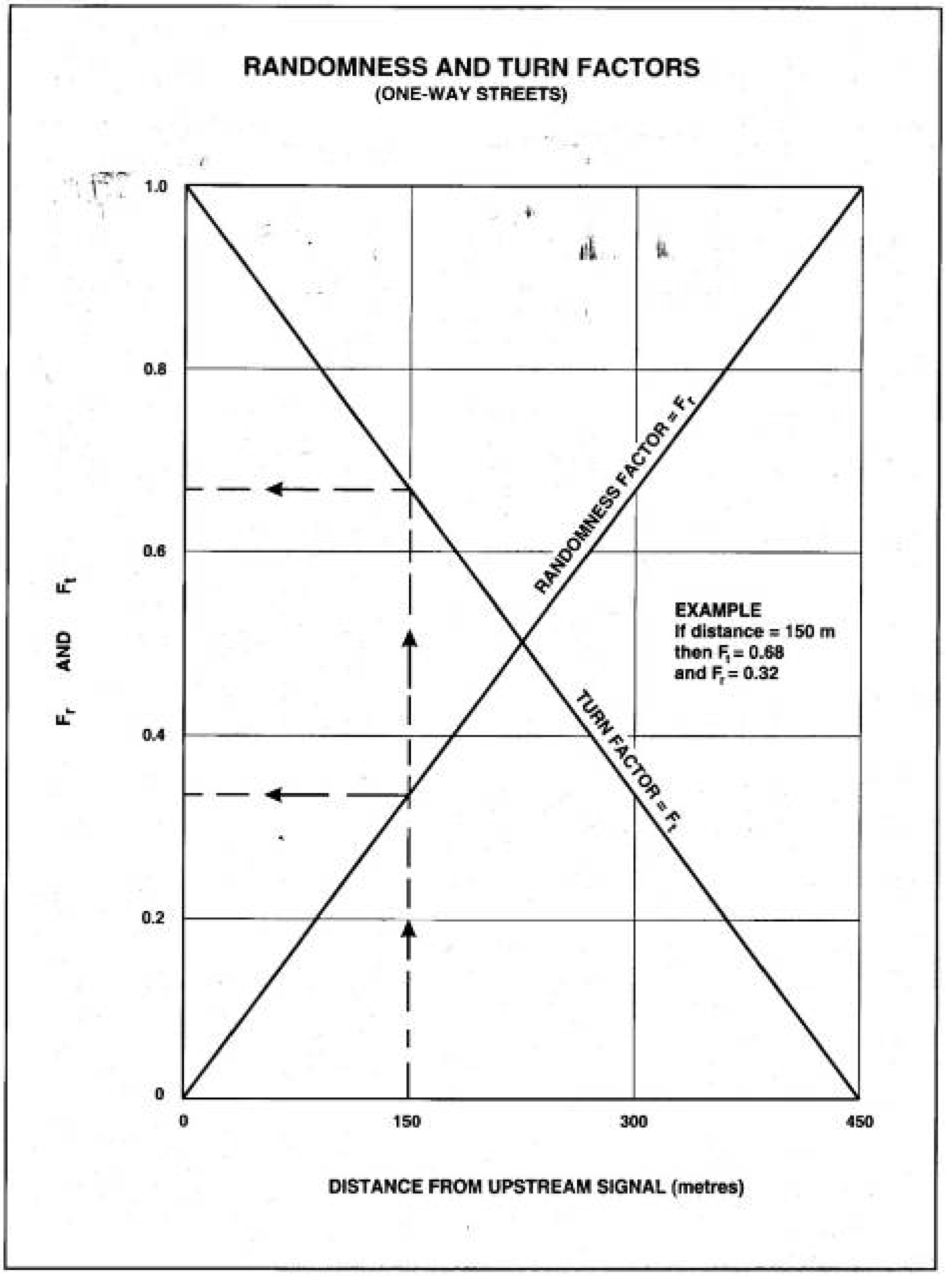


FIGURE B2-4

SEPTEMBER 1998

FIGURE B2-5

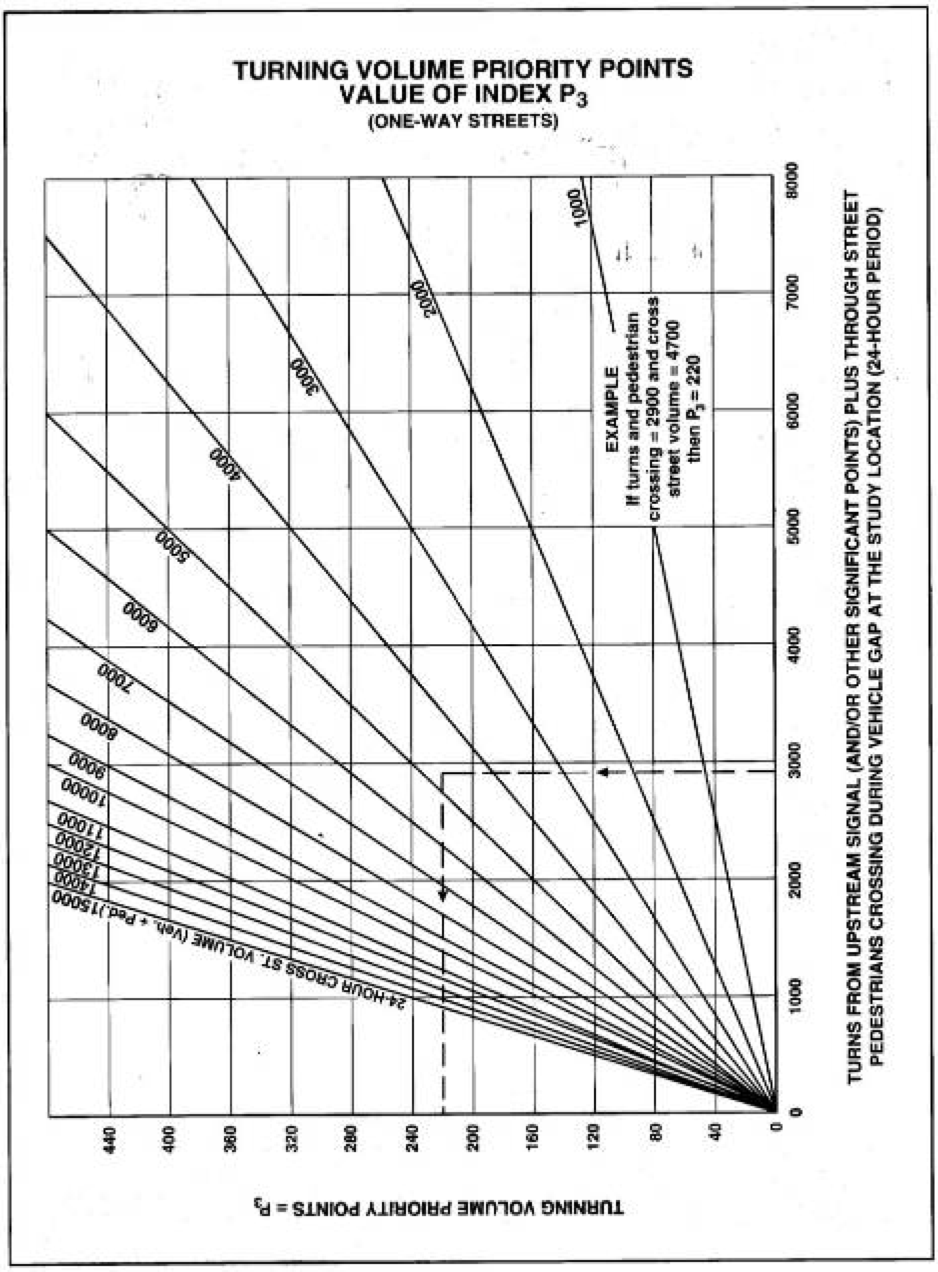


FIGURE B2-5

SEPTEMBER 1998

MANUAL OF UNIFORM TRAFFIC CONTROL DEVICES FOR CANADA

TRAFFIC SIGNALS
INSTALLATION GUIDELINES
B2

FIGURE B2-6

TRAFFIC CONTROL SIGNAL INSTALLATION WARRANT AND PRIORITY RATING WORK SHEET

Location ______________ Year _________ Date of Count ______________

I Collisions (Figure B2-1)

Priority points = P_a ____

II Crossing Gaps, Progression, Delay and Vehicular Stops

A. One-Way Street (Figure B2-2)

Priority points	=	P_1	x	V_{tew}	x	F_{eew}			
E-W Street - E. of int.	=	___	x	___	x	___	=		___
E-W Street - W. of int.	=	___	x	___	x	___	=		___
Priority points	=	P_1	x	V_{tns}	x	F_{ens}			
N-S street - N. of int.	=	___	x	___	x	___	=		___
N-S street - S. of int.	=	___	x	___	x	___	=		___

B. Two-Way Street (Figure B2-3)

Priority points =	=	P_2	x	V_{tew}	x	F_{eew}			
E-W Street - E. of int.	=	___	x	___	x	___	=		___
E-W Street - W. of int.	=	___	x	___	x	___	=		___
Priority points	=	P_2	x	V_{tns}	x	F_{ens}			
N-S street - N. of int.	=	___	x	___	x	___	=		___
N-S street - S. of int.	=	___	x	___	x	___	=		___ ___*

III Crossing Gaps, Intersecting Volumes, and Pedestrian Volumes

A. Through Street One-Way (Figures B2-4 and B2-5)

1). Priority points

$= (V_{aew} + P_{ew}) \times (V_{ans} + P_{ns}) \times F_{ow} \times F_r$

= (___ + ___) x (___ + ___) x ___ x ___ = ___

2). Priority points

$= P_3 \times F_t$ = ___

B. Through Street Two-Way

Priority points

$= (V_{aew} + P_{ew}) \times (V_{ans} + P_{ns}) \times F_{ow}$

= (___ + ___) x (___ + ___) x ___ = ___ ___

TOTAL PRIORITY POINTS ______

NOTE: Complete I; the appropriate equation for each intersection leg in Section II A and/or II B; and either Section IIIA or III B.

* **Maximum points for II = + 80**

FIGURE B2-6

SEPTEMBER 1998

SOUTH AFRICA (*102*)

In recent years, the warrants for the provision of pedestrian signal heads have undergone a major change in the sense that the conditions under which these facilities are provided are based on engineering judgment of an intersection instead of a fixed volume warrant. The following are typical conditions under which pedestrian signal heads are now considered in South Africa:

- When traffic volumes or turning traffic are so high as to require a leading pedestrian phase,
- When advance or extended green vehicular phases permit turning movements across a pedestrian crossing,
- When no signal heads for vehicles are provided opposite pedestrian crossings (e.g., at one-way streets), and
- When pedestrians are confused at large or complicated intersections.

An analysis of road accident statistics showed that more than half of all pedestrians involved in road accidents crossed the road at points where no pedestrian crossings existed. A study to investigate the effectiveness of the existing midblock pedestrian crossing system found the following deficiencies:

- Lack of uniformity in the provision of unsignalized and signalized midblock pedestrian crossings contributed to the inconsistent provision of facilities.
- Poor conspicuity of these crossings contributed to an unsafe situation at these crossings.

To address the problem of the inconsistent provision of pedestrian crossings, warrants were developed for the provision of yield sign-controlled (type of unsignalized crossing) and traffic signal-controlled midblock pedestrian crossings. These warrants consider a number of traffic and pedestrian characteristics such as one- versus two-way roads, roadway width to be crossed, speed limit, and pedestrian walking speed for different age groups. To test the warrants, they were applied to a number of high accident frequency spots where no pedestrian crossings existed. They were also applied to crossings where large numbers of pedestrians were crossing roads. It was shown that pedestrian crossings were needed at several of the sites without crossings and several of the existing crossings were in need of upgrades.

AUSTRALIA (*103*, *104*, *105*)

The Australian Standard *Manual of Uniform Traffic Control Devices* and the Austroads *Guide to Traffic Engineering Practice* provide a set of guidelines for the control and protection of pedestrians. In practice they are used as guidelines and are not legally enforceable. The draft *Australian Road Rules* has a number of sections relating to pedestrians. The *Australian Road Rules* will not be enforceable until legislated by Federal Parliament. It is expected that the rules will then become an Australia-wide standard, replacing current traffic regulations in each of the states.

The Australian Standard (AS) 1742.10-1990 *Manual of Uniform Traffic Control Devices,* Part 10: Pedestrian Control and Protection, sets out requirements for traffic control devices to be used in the control and protection of pedestrian traffic on roads. It specifies the way in which these are used to achieve pedestrian control. The manual includes definitions, installation details, clause references, and references to other applicable standards. Requirements for the illumination and reflectorization of signs, their installation, location, and size are outlined in the appendixes. Details are also included on model instructions for adult supervisors and child monitors at children's crossings, pedestrian-actuated traffic signals, and pedestrian treatments at railway level crossings. The relevant material of AS1742.10 is shown in Table G-2.

TABLE G-2. Portions of Material from Australian Standard (AS) 1742.10-1990.

6.3 Children's Crossings

6.3.1 *Installation* The distinctive feature of a children's crossing is its part-time nature, being designed to operate as a crossing only at such times as when one or more CHILDREN'S CROSSING flags (R3-3) (see Clause 10.1.5) are displayed to vehicular traffic.

This type of crossing, which includes use of posts painted in red and white alternate bands, is usually installed near school locations where the requirements for such a facility arise only during specific and limited times of the school day.

A children's crossing may be supplemented by twin alternating flashing yellow signals at or in advance of the crossing.

A children's crossing may be supervised during the times when it is operational, in which case, subject to State regulations, the hand STOP Banner (R6-7) may be used (see Clause 10.1.10).

6.3.2 *Guidelines for installation* The children's crossing may be installed where there is a demand for children to cross the road during daylight hours and an undertaking can be obtained to display the CHILDREN CROSSING flags (R3-3) during, and only during, the specified period of operation (see Clause 10.1.5).

Before installing a children's crossing on an arterial road, the matter should be carefully considered.

6.4 Pedestrian actuated traffic signals (mid-block)

6.4.1 *Installation* Pedestrian actuated traffic signals (mid-block) shall comply with AS 2144 and pedestrian push buttons with AS 2353.

The line marking and sign arrangement for a mid-block pedestrian actuated traffic signal installation is shown in Figure 3.

The absence of the usual intersection cues in relation to mid-block signals necessitates a particularly high standard of signaling. Mast-arm or median island signals may need to be installed on carriageways with more than three lanes in one direction. The principles for installation of the signals are given in AS 1742.2.

A signalized crossing may be supervised during the times when it is used by significant numbers of school children. The hand STOP Banner is NOT used at traffic signals.

TABLE G-2. Material from Australian Standard (AS) 1742.10-1990 (continued).

6.4.2 *Guidelines for installation* Pedestrian-actuated traffic signals (midblock) may be provided if any of the following conditions exist:

(a) The pedestrian volume exceeds 350 persons per hour for each of 3 hr on an average day, and during each of the same 3 hr the traffic volume exceeds 600 veh/h (total both directions), or 1000 veh/h (total both directions) where there is a central pedestrian refuge.
(b) For each of 8 hr of an average day –
  (i) the traffic volume on the road exceeds 600 veh/h (total both directions), or 1000 veh/h (total both direction) where there is a central pedestrian refuge; and
  (ii) during the same 8 hr the pedestrian volume is 175 or more persons per hour; and
  (iii) there is no other pedestrian crossing, footbridge or subway within a reasonable distance.
(c) At a school where, in two separate 1 h periods of a typical school day, there are no fewer than 50 persons crossing the roadway and at least 600 vehicles pass the site subject to the product of the number of pedestrians per hour and vehicles in the same hour exceeding 40,000.
(d) The pedestrian and traffic volume is sufficient to justify a pedestrian crossing but pedestrians would be in danger on an “unprotected” pedestrian crossing. This could be due to the width of carriageway, traffic speed, or traffic volume
(e) A pedestrian crossing exists and two or more pedestrian accidents of a type susceptible to correction have occurred on or near the crossing within the past three years.
(f) A pedestrian crossing is justified and pedestrian volumes are very heavy and coincide with high traffic volumes to the extent that excessive delays to road traffic are likely.

In addition to the above, if the guidelines for the provision of a pedestrian crossing (zebra) are met and the site is either adjacent to a railway level crossing, close to a signalized intersection on an arterial road, or within a coordinated traffic signal system, consideration should be given to the use of pedestrian actuated signals instead of the pedestrian crossing (zebra).

For signals which cater mainly for persons with particular disabilities, e.g., aged, blind, deaf, or disabled persons, the above warrants may be modified to make allowance for the different characteristics of the pedestrian traffic.

Where appropriate, pedestrian-actuated traffic signals (midblock) should be coordinated with intersections signals or railway level crossing signals. If it is necessary to install midblock signals in such close proximity to an intersection or railway level crossing that queuing is likely to occur across the intersection or railway level crossing, the signal controls at the two points should be coordinated to obviate such queuing. The need to keep pedestrian delays to a minimum should also be considered.

TABLE G-2. Material from Australian Standard (AS) 1742.10-1990 (continued).

Intersection traffic signals should be considered if a pedestrian-actuated signal meeting the above requirements is to be located at or close to an intersection. However, account should be taken of the possible traffic impacts of such intersection signals on local streets within the adjacent area.

6.5 Pelican crossings

6.5.1 *Installation* The requirements for the installation of a pelican crossing are the same as for pedestrian-actuated traffic signals (midblock) as given in Clause 6.4.1. The line marking and sign arrangements are the same as those shown in Figure 3.

6.5.2 *Guidelines for installation* The main advantage of Pelican crossings is the reduced delay to vehicles. Studies have shown that vehicle delays at Pelican crossings are approximately half those at conventional pedestrian-actuated signals. Pelican crossings may therefore be provided if –

(a) pedestrian-actuated traffic signals (midblock) are justified;
(b) the site would benefit from reduced vehicle delays; and
(c) the site is in an area where the 85^{th} percentile speeds are less than 49.7 mph (80 km/h).

APPENDIX H

ADEQUACY OF PEDESTRIAN SIGNAL WARRANT

As part of Phase I, the research team evaluated the adequacy of the pedestrian signal warrant. This Appendix provides the history of the pedestrian traffic signal warrant and an analysis of the adequacy of the pedestrian signal warrant contained in the Millennium Edition (*91*) and the 2003 Edition (*1*) of the *MUTCD*.

BASIS OF THE PEDESTRIAN SIGNAL WARRANT

A form of the pedestrian signal warrant has been included in every version of *MUTCD* dating back to the first Manual in 1935. Table H-1 summarizes the warranting criteria needed to satisfy the pedestrian signal warrant as it has evolved in the past 70 years. Figure H-1 shows the current language.

Starting at the inception of the warrant in 1935, the warranting criteria were becoming increasingly difficult to satisfy up to a maximum difficulty level in 1961. For the next 27 years the warranting criteria remained unchanged while the Manual underwent significant updates. The 1988 Manual included a major shift in the pedestrian warranting criteria. It is probably no coincidence that the majority of the published research related to the pedestrian signal warrant was conducted during the 1970s and early 1980s. A detailed review of these studies is included in TxDOT Report 2136-1 (*106*).

In 1988, the signal warrant criteria were amended to make them more responsive to the needs of pedestrians, the elderly, and the handicapped. The changes were based in part on two FHWA-sponsored research studies (*107, 108*) but also included modifications from the National Committee on Uniform Traffic Control Devices (NCUTCD) because it was felt that the research recommendations did not adequately reflect the negative tradeoffs of installing pedestrian signals (from: FHWA Official Ruling IV-60 [Change], 1988). The main problem with the pre-1988 pedestrian warrant was the requirement to have 150 or more pedestrians on the highest volume crosswalk crossing the major street for an 8-hr period. Converting this requirement to daily pedestrian volumes yields approximately 7600 pedestrians crossing four legs of a typical intersection or 2700 pedestrians per day crossing a midblock location.

Another philosophy of the time was that pedestrians desiring to cross the major roadway faced a similar situation as vehicles on the minor approach waiting to cross the major. In fact, the lack of any relationship to the number of adequate gaps was cited in Official Ruling IV-60(c) as one of the key reasons for change the pedestrian warrant criteria in 1988. Gap-based warrants were also the focus of one of the earlier pedestrian warrant studies (*108*).

TABLE H-1. Evolution of the Pedestrian Warrant Criteria.

***MUTCD* Year**	**Warranting Conditions**
1935, 1939	The minimum pedestrian and vehicular volumes ... are as follows: < Pedestrian volume crossing the major street must average at least 300 ped/h for at least 6 hr per day, < Vehicular traffic entering the intersection from the major street must average at least 750 veh/h for the same 6 hr, and < Vehicular speeds during the 6 hr must frequently exceed 15 mph (24 km/h).
1942	The minimum pedestrian and vehicular volumes ... are as follows: < Pedestrian volume crossing the major street must average at least 300 ped/h for at least 6 hr per day and < Vehicular traffic entering the intersection from the major street must average at least 750 veh/h for the same 6 hr.
1948	In urban areas: < Pedestrian volume crossing the major street must average at least 250 ped/h for any 8 hr of an average day, and < Vehicular traffic entering from the major street must average at least 600 veh/h for the same 8 hr, and < The average vehicle speed must exceed 15 mph (24 km/h) on the approaches to the intersection. In rural areas: < Pedestrian volume crossing the major street must average at least 125 ped/h for any 8 hr of an average day, and < Vehicular traffic entering from the major street must average at least 300 veh/h for the same 8 hr, and < The average vehicle speed must exceed 30 mph (48 km/h) on the approaches to the intersection.
1961, 1971, 1978	This warrant is satisfied when for each of any 8 hr of an average day, the following volumes exist: < On the major street, 600 veh/h or more enter the intersection (total of both approaches); or 1000 veh/h or more (total of both approaches) enter the intersection on the major street where there is a raised median island 4 ft or more in width; and < During the same 8 hr as in paragraph 1, there are 150 ped/h or more on the highest volume crosswalk crossing the major street. When the 85th percentile of major street traffic exceeds 40 mph (64 km/h), or when the intersection lies within the built-up area of an isolated community having a population of less than 10,000, the minimum pedestrian volume warrant is 70 percent of the requirements above, in recognition of the differences in the nature and operational characteristics of traffic in urban and rural environments and smaller municipalities.
1988, 2000, 2003	A traffic signal may be warranted where the pedestrian volume crossing the major street at an intersection or midblock location during an average day is: < 100 or more for each of any 4 hr, or < 190 or more during any 1 hr. The pedestrian volume crossing the major street may be reduced as much as 50 percent of the values given above when the predominant pedestrian crossing speed is below 4.0 ft/sec. In addition to the volumes stated above, there shall be less than 60 gaps/hr in the traffic stream of adequate length for pedestrians to cross during the same period when the pedestrian volume criterion is satisfied.

Section 4C.05 Warrant 4, Pedestrian Volume

Support:
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.

Standard:
The need for a traffic control signal at an intersection or midblock crossing shall be considered if an engineering study finds that both of the following criteria are met:

- **A. The pedestrian volume crossing the major street at an intersection or midblock location during an average day is 100 or more for each of any 4 hours or 190 or more during any 1 hour; and**
- **B. There are fewer than 60 gaps per hour in the traffic stream of adequate length to allow pedestrians to cross during the same period when the pedestrian volume criterion is satisfied. Where there is a divided street having a median of sufficient width for pedestrians to wait, the requirement applies separately to each direction of vehicular traffic.**

The Pedestrian Volume signal warrant shall not be applied at locations where the distance to the nearest traffic control signal along the major street is less than 300 ft (90 m), unless the proposed traffic control signal will not restrict the progressive movement of traffic.

If this warrant is met and a traffic control signal is justified by an engineering study, the traffic control signal shall be equipped with pedestrian signal heads conforming to requirements set forth in Chapter 4E.

Guidance:
If this warrant is met and a traffic control signal is justified by an engineering study, then:

- A. If at an intersection, the traffic control signal should be traffic-actuated and should include pedestrian detectors.
- B. If at a nonintersection crossings, the traffic control signal should be pedestrian-actuated, parking and other sight obstructions should be prohibited for at least 100 ft (30 m) in advance of and at least 20 ft (6.1 m) beyond the crosswalk, and the installation should include suitable standard signs and pavement markings.
- C. Furthermore, if installed within a signal system, the traffic control signal should be coordinated.

Option:
The criterion for the pedestrian volume crossing the major roadway may be reduced as much as 50 percent if the average crossing speed of pedestrians is less than 4 ft/s (1.2 m/s).

A traffic control 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, even if the rate of gap occurrence is less than 1 per minute.

Figure H-1. Current Pedestrian Signal Warrant (*1*).

The gap concept is based on the hypothesis that a pedestrian must wait for an adequately sized gap and, as the number of adequate gaps decreases, pedestrians experience more delay. If the waiting time becomes excessive, the pedestrian may become impatient and may even step off the curb onto the road to force a gap. This behavior would obviously be undesirable and unsafe. It was reasoned that there is a point when the pedestrian waiting time become intolerable. This was termed acceptable pedestrian delay and a value of 60 seconds was more or less arbitrarily chosen.

The minimum pedestrian volume threshold was maintained to reflect the negative tradeoffs associated with the installation of a traffic signal (such as vehicle delay on the major road). Previous research had recommended values ranging from equivalent daily pedestrian volumes of 1200 at an intersection and 760 at midblock locations (*107*). The NCUTCD reviewed these recommendations and decided that they would result in an excessive number of traffic signals. They recommended, and the FHWA adopted, equivalent daily pedestrian volumes of 2000 at an intersection and 1250 at a midblock crossing. These criteria are derived from the current criteria of 100 pedestrians or more for each of any 4 hours of an average day and 190 or more pedestrians crossing the major street.

In an attempt to accommodate the elderly and handicapped, Zeeger et al. (*107*) recommended a new warrant separate of the pedestrian warrant. The NCUTCD reviewed the proposed warrant and ultimately decided to work it into the revised pedestrian warrant of 1988 by including a pedestrian volume reduction factor based on walking speed. The FHWA adopted their recommendation rather than developing a new warrant for a specific class of pedestrians.

The vehicle gap, pedestrian volume, and walking speed criteria discussed in the immediate paragraphs were introduced into the *MUTCD* in 1988. The pedestrian warranting criteria did not change with the release of the Millennium Edition of the *MUTCD* or the 2003 Edition.

CRITIQUE OF THE PEDESTRIAN SIGNAL WARRANT

The current pedestrian warrant has many factors that are to be considered when evaluating whether 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 are based on the type of requirement as indicated in the language of the *MUTCD* and the relevance to the issue being studied. Primary factors are those factors that must be considered and they include available vehicular gaps (based on critical gap), pedestrian volume, and distance to the nearest traffic signal. A secondary factor is the adjustments to pedestrian volumes based on the average walking speed. Other factors in the current pedestrian signal warrant considered not relevant to this research project include type of pedestrian signal heads, coordination, actuation, detection, parking, signing, and markings.

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

Other needed attributes of the warrant could be a reference to alternative traffic control and how to determine the size of the adequate gap length. The guidance section 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 would provide the user with the preferred method for determining the value. It would also show sensitivity to number of lanes and walking speed. The *HCM* (*109*) contains a method to calculate critical gap for a single pedestrian or a group critical gap in Chapter 18 and could be referenced.

The following discusses and critique the key factors introduced above.

Primary and Secondary Factors

Vehicular Gap

The introduction of the gap criterion in 1988 was a significant change in philosophy. Because of variations in traffic signal timing plans, platooning, and platoon decay, a roadway with the same traffic volume can have different gap distributions. By using the gap criterion, local conditions are considered. However, the current 60-second criterion is derived from ITE's school crossing guidelines (going back to 1962). The guidelines were based on an old but common traffic signal timing scheme of fixed 60-second cycles. The 1962 ITE guidelines state that traffic control is needed when the number of adequate gaps is less than the number of minutes in the same period of time. In other words, it was assumed that gaps less frequent than one per minute represent an unsatisfactory situation. This assumption has not been tested or documented. It is important to note that in today's downtown areas (or other areas normally associated with pedestrian activity) it is very difficult to maintain 60-second cycle lengths because of pedestrian phasing and left-turn phasing. It is also important to note that the *HCM* indicates that the likelihood of risk-taking behavior by pedestrians is very high when pedestrian delay is at 45 seconds.

The gap criterion needs to be investigated. Adjustments to the gap criterion may be needed based on factors such as difficulties in judging gap because of pedestrian age, pedestrian disabilities, relationship of number of acceptable gaps to risk-taking behavior, vehicle speed, number of lanes being crossed, etc. A part of the investigation should be to examine whether vehicular volume rather than gaps could be appropriate for use in the warrant.

Pedestrian Volume

There are certainly countless locations where adequate gaps occur in the major street less frequently than one per minute. To account for the negative safety and operations impacts of installing too many traffic signals, a lower bound was set using pedestrian volume as the criterion. The current pedestrian volumes are higher than most of the previous research recommendations, which were developed based on different factors. In general, however, two sets of recommendations have been based on pedestrian delay.

- NCHRP 3-20 and King: 100 ped/h for 4 hr
- Box: 60 ped/h for two 30-min periods.

Two more sets of recommendations have been based on pedestrian crash analyses:

- Zeeger: 60 ped/h for 4 hr, 90 ped/h for 2 hr, and 110 ped/h for 1 hr
- Neudorff: 60 ped/h for 4 hr, 90 ped/h for 2 hr, and 110 ped/h for 1 hr

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 hr 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. One difference between the two approaches 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 comparison of the lower threshold volumes is shown in Table H-2. For example, an intersection with only 100 vehicles for the peak hour would warrant a signal before a midblock location with 190 ped/h. When the 70 percent factor is used, the difference becomes even more pronounced, an intersection could warrant a signal with only 75 veh/h while 190 ped/h would still be required. This comparison assumes a quite high number of vehicles on the major road; however, it does demonstrate a difference between vehicles and pedestrians.

The 190 ped/h represents a single pedestrian every 19 seconds. In this condition the pedestrians would probably cross in groups, which could be a better comparison to vehicles. Perhaps the warrant should consider pedestrian groups rather than individual pedestrians.

In summary, the vehicle warrants use a sliding scale while the pedestrian warrant uses absolute values. The absolute values are higher than the lower threshold values assumed for vehicles. The vehicle warrants also include a reduction factor for population and major roadway speed which is not present in the pedestrian warrant.

TABLE H-2. Comparison of Vehicle and Pedestrians Threshold Values.

Condition	Number of Lanes on Minor Road Approach	Lower Threshold Volume (Pedestrian or Vehicle on Minor Approach)			
		Peak Hour		Four Hour	
		Warrant 3 [b] Vehicular (veh/h)	Warrant 4 Pedestrian (ped/h)	Warrant 2 [c] Vehicular (veh/h)	Warrant 4 Pedestrian (ped/h)
Warrant	2 or more	150	190	115	100
	1	100		80	
70% Factor [a]	2 or more	100	190	80	100
	1	75		60	

[a] For communities <10,000 population or >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 1450 veh/h.
[c] The minimum minor road volume occurs when the major street volume is approximately 1100 veh/h or more or at 800 veh/h when the community is <10,000 or the speed on the major is >40 mph (64 km/h).

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. Department of Transportation's 1995 Nationwide Personal Transportation Survey (*110*) did find that the majority of pedestrian trips (73 percent) are 0.5 mi (0.81 km) or less. With most trips being about 2600 ft (793 m), one could suspect that many pedestrians would be unwilling to increase their trip length by more than 10 percent in order to walk to a different crossing location.

As part of on-street pedestrian surveys (see Appendix I), 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 that was located at 550 ft (168 m), 950 ft (290 m), or 1000 ft (305 m). For the site with a signalized intersection about 200 ft (61 m) from the crossing, about half 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 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 upon the weather or other factors.

Reduction Criteria Based on Walking Speeds

In the current warrant, the only reduction factor for the warranting criteria is based on walking speed and it only affects the pedestrian volume criterion. This concept was introduced in order to accommodate the elderly and handicapped. Specifically, if the average walking speed is less than 4 ft/s (1.22 m/s) then a reduction on the pedestrian volume of up to 50 percent can be implemented.

Pedestrians have a wide range of needs and abilities. The *MUTCD* includes a comment that where pedestrians who walk slower than normal, or pedestrians who use wheelchairs, routinely use the crosswalk, a walking speed of less than 4.0 ft/s (1.22 m/s) should be considered in determining the pedestrian clearance times. Other research studies have identified pedestrian walking speeds ranging from 2.0 ft/s (0.6 m/s) to 4.3 ft/s (1.3 m/s). The *HCM* states that pedestrian walking speed depends on the proportion of elderly pedestrians (65 years of age and older) in the walking population. They provide the following for determining walking speed:

Walking Speed	% elderly pedestrians
4 ft/s	0 to 20
3.3 ft/s	>20 to 30
3.0 ft/s	>30 to 40

Decrease walking speed by 0.3 ft/s (0.1 m/s) for every addition 10 percent increase in elderly pedestrian population.

It is reasonable to question the walking speeds in the *MUTCD*, especially considering disabled pedestrians, child pedestrians, and elderly pedestrians (all frequent users of transit). It is also reasonable to consider how crossing speed may be correlated to such factors as type of traffic control (several previous studies were at signalized rather than unsignalized intersections), type of pedestrian generator (e.g., transit, senior citizen home, etc.), vehicle speed, roadway cross section, number of pedestrians, pedestrian age, etc.

POTENTIAL FACTORS

Pedestrian Generators (Transit Stops)

The closeness of a pedestrian generator is not considered within the current pedestrian signal warrant. Examples of pedestrian generators include schools of all levels, senior citizen homes, and transit stops. There is obviously a periodic generation of pedestrian at a transit stop and although the volumes may not be steady, they may be significant for short burst of time.

School Warrant

The school signal warrant has a unique feature that may possibly lend itself quite nicely to the handling of all pedestrian crossing treatments. In the school warrant, the main consideration is the ratio between 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. For instance, when fewer adequate gaps exist than are needed, a system could be developed that uses the level of deficiency to select the crossing treatment. The crossing treatments and deficiency scores would be ranked in a less to more restrictive order with the traffic signal being the most restrictive.

Crash Experience

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. It may be reasonable to include a factor within the warranting criteria that considers safety in terms of pedestrian-related crashes, especially because of the vulnerability associated with pedestrian crashes. Pedestrians are involved in less than 1 percent of all crashes, but yet they account for 18 percent of highway fatalities (Minnesota).

Counting Pedestrians on the Minor Approach with Vehicular and Bicycle Volumes

Other research (*106*) has recommended more global changes to the way pedestrians are handled in the signal warranting criteria. The recommendations include counting pedestrians on the minor approaches as vehicles and bicycles are counted now. This would change the vehicular-based warrants to all mode, intersection-based warrants. It would also allow the pedestrian warrant to focus on just the midblock crossing, which would make the warrant more straightforward.

The largest issue that needs to be considered is how to count pedestrians versus vehicles. The pedestrians are exposed to inclement weather conditions, they have slower acceleration and speed rates resulting in longer crossing times, and they are at considerably more risk than occupants of vehicles, especially as the major street speeds increase. Therefore, it seems reasonable to develop an equivalency factor for pedestrians at intersections.

This concept could be simply where one pedestrian might count as three vehicles, or it could be more complex, depending on the age or walking speed of the pedestrian. Critical gaps for vehicles and pedestrians are provided in the *Highway Capacity Manual* (*109*) and the AASHTO *Green Book* (*111*). Table H-3 lists the critical gaps to cross a sample roadway. A pedestrian requires more time to cross an intersection than a vehicle. To cross a two-lane roadway, a pedestrian needs 39 percent more time (potential factor of 1.4). At a four-lane street, a pedestrian needs twice as much time, or a potential factor of 2.0. Canada's pedestrian signal procedure includes equivalent adult units with children and disabled counting as 2.0 adults and seniors counting as 1.5 adults.

TABLE H-3. Critical Gaps for Vehicle and Pedestrian at an Unsignalized Intersection.

Through	Critical Gaps	
	Vehicle (sec)	Pedestrians (sec)
Two lane	6.5	9
Four lane	7.5	15
Source	*Green Book* Exhibit 9-57, assume passenger car	*HCM* Equation 18-17, assume 12 ft (4 m) lanes, 4 ft/s (1.22 m/s) walking speed, and 3 sec start up

It is important to note that the concept of counting all road users on the minor street approach is not novel to the *MUTCD*. The current *MUTCD* multiway Stop warrant has a criterion that includes the summation of vehicles, bicycles, and pedestrians on the minor street approach. There is not an equivalency factor considered for pedestrians in the multiway Stop warrant, in other words, one pedestrian counts similar as one car. Also, there is not a reduction of the number of pedestrians or bicycles to account for when a pedestrian or bike crosses at the same time as a car.

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. As shown in Table H-1, the pedestrian signal warrant also included the same reduction factor until the 1988 revision. It should be noted that there is not a discussion in *FHWA Final Rule IV-60 (Change) 1988* that describes the reasons that the vehicle speed reduction factor was dropped.

Increased vehicle speeds represent additional challenges for pedestrians. Pedestrian fatality rates and injury rates increase as vehicle speed increases. Pedestrians also have a harder time judging adequate gaps as vehicle speeds increase.

Pedestrian Delay

The *Highway Capacity Manual* includes a procedure to estimate pedestrian delay for unsignalized intersection. It begins with calculating critical gap, which is defined as the time in seconds below which a pedestrian will not attempt to begin crossing the street. Critical gap is a function of average pedestrian walking speed, crosswalk length, and pedestrian start-up time and end clearance time. If platooning is observed in the field, the *HCM* provides the needed equations for determining the group critical gap.

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. *HCM* Exhibit 18-13 (reproduced as Table H-4) is then used to determine the LOS of the crossing. A signal warrant could be developed based on a function of the pedestrian delay. For example, if a pedestrian is experiencing LOS F conditions, then a signal could be considered. Other measures could be a total pedestrian delay value or the warrant could require a minimum number of pedestrians at the site. For ease of use and based on user preference for only counting vehicles or pedestrians, pedestrian and vehicle volumes would need to be identified to represent the selected delay threshold(s).

Warrant 3 (Peak Hour) also includes delay criteria for traffic on one minor-street approach (one direction only). Total stopped time delay is to exceed 4 vehicle-hours for a one-lane approach or 5 veh-h for a two-lane approach. The volume on the same minor-street approach is to equal or exceed 100 veh/h for one moving lane of traffic or 150 veh/h for two moving lanes. (There is also a total entering criteria.) The minor road numbers represents average delays of 2.4 and 2.0 minute for a vehicle for one- and two-lane approaches, respectively. These delay values are much higher than what is assumed that pedestrians would tolerate; however, this concept represents another feasible approach for warranting a pedestrian signal.

TABLE H-4. Reproduction of *HCM* Exhibit 18-13: LOS Criteria for Pedestrians at Unsignalized Intersections.

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.

USAGE OF THE PEDESTRIAN SIGNAL WARRANT

Before the pedestrian signal warrant was significantly revised in 1988, a study documented its relative use (*112*). Only 1.3 percent of 12,780 traffic signal installations surveyed were justified using the 1961 version of the pedestrian warrant.

Another more recent survey (*106*) assessed the relative usage of the 1988 version (which reflects the current version) of the pedestrian signal warrant. This survey only asked about the previous 3 years worth of traffic signal installations. The survey was sent to state agencies and local agencies. No state agency had used the pedestrian signal warrant as the primary warrant to justify the installation of a signal (32 states responded). Of the 50 local agencies reporting, only 2 percent of the signal installations were based primarily on the pedestrian signal warrant. Combined, these data represent over 3500 signal installations.

These data indicate that the usage of the pedestrian signal warrant has remained low despite significant changes in 1988. While the data were not collected or reported in a similar fashion between the two studies, the findings appear reasonable. Only a few candidate traffic signals are evaluated solely on the basis of pedestrian needs because the majority of intersections with heavy pedestrian activity, such as downtown areas, already satisfy one or more of the vehicular signal warrants. However, it is important to note that the need for traffic signals at midblock crossings would not consider side vehicle traffic only pedestrian needs.

CONCLUSIONS

Several elements with respect to the pedestrian signal warrant could benefit from additional investigation. This paper presented background information and a critique of the various factors associated with the pedestrian signal warrant. Following is a summary of those issues that could warrant additional research.

- **Vehicular gap**: Is the current gap criterion reasonable? What is the relationship between the number of acceptable gaps and risk-taking behavior? Should adjustments to the criterion be made for pedestrian capabilities (e.g., judging ability, disabilities, etc.) vehicle speed, number of lanes being crossed, or others?
- **Pedestrian Volume**: The current pedestrian volumes are higher than most of the previous research recommendations. They can also be higher than vehicle volumes in other signal warrants in certain scenarios. The vehicle warrants also use a sliding

scale (minor road and major road volumes change), while the pedestrian warrant has only one set value regardless of the volume on the major road. Should the pedestrian volume values be lower? Should it be on a sliding scale?

- **Reduction Factor**: The vehicle warrant includes a reduction factor for communities with less than 10,000 population or speeds above 40 mph (64 km/h) on the major street. Should this reduction factor also be present in the pedestrian signal warrant?
- **Pedestrian Groups**: Should the warrant consider pedestrian groups rather than individual pedestrians? As the number of pedestrians crossing increases, they would begin to cross in groups rather than as individuals.
- **Distance to Nearest Traffic Signal**: What is a reasonable distance that pedestrians can be expected to walk to cross at a controlled location?
- **Walking Speed**: What is a reasonable walking speed for unsignalized crossings for different user groups? How does the walking speed vary by major roadway speed, number of lanes being crossed, number of pedestrians, type of traffic control, pedestrian age, etc.?
- **Ratio of adequate gaps to minutes crossing is used**: Is the approach used in the school warrant appropriate for any pedestrian crossing?
- **Pedestrian Generators**: How should selected pedestrian generators, such as schools, transit stops, or senior citizen homes, be considered within the warranting process?
- **Accidents**: Should the pedestrian signal warrant include consideration of pedestrian accidents?
- **Pedestrians on Minor Road Approach**: Should pedestrians be included in determining the minor road demand as vehicles and bicycles are now?
- **Pedestrian Equivalency**: Should the warrants include a pedestrian equivalency factor? Pedestrians are exposed to inclement weather conditions, have slower acceleration and speed rates resulting in longer crossing times, need longer critical gaps, and are at considerably more risk than occupants of vehicles, especially as the major street speeds increase.
- **Pedestrian Delay**: Should the pedestrian warrant be more directly based on pedestrian delay? If so, is 60 seconds appropriate or should it be changed to 45 seconds, which is used to determine LOS F in the *HCM*? Or is another value more appropriate? What is the relationship between delay and risk behavior, street width, and other variables?
- **Excessive Number of Signals**: A concern with any change to the signal warrants is whether it will result in an excessive number of signals or in signals that are very disruptive to the effective flow of all traffic. How can those issues be investigated?

APPENDIX I

SUGGESTED ISSUES TO CONSIDER WHEN REVISING THE PEDESTRIAN SIGNAL WARRANT

The *MUTCD* (*1*) is the national standard for traffic control devices on all public roads. It states that the selection and use of traffic control signals should be based on an engineering study of roadway, pedestrian, bicyclist, and other conditions. This engineering study would include consideration of the traffic signal warrants present in the *MUTCD*. The 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 engineer's judgment toward the traffic signal warrants (or toward proposed revisions to the traffic signal warrants) are needed.

One such approach to reviewing engineer's judgment would identify potential sites to be considered in an evaluation. The characteristics of the sites would be provided to traffic engineers who have agreed to participate in the study. They would be asked to visit the sites and provide their engineering judgment as to whether a traffic signal is needed. They would also be asked to provide their opinions on other treatments that could be appropriate for the site. The unique requirements of the study approach include: (a) being in an area where a large number of traffic engineers will be congregating, (b) having a sufficient number of potential sites (i.e., sites that have qualities where a signal would be considered), and (c) having the potential study sites be within a reasonable driving distance (since the participants would need to visit each site).

The TCRP/NCHRP D-08/3-71 study on *Improving Pedestrian Safety at Unsignalized Intersection* has as an objective to recommend modifications to the *MUTCD* pedestrian traffic signal warrant. Using an assessment of the criteria considered when determining whether a traffic signal should be installed was one of the approaches used in the TCRP/NCHRP study to identify potential changes to the traffic signal warrant.

PREVIOUS EFFORT

A Texas study (*106*) recruited six department of transportation, seven city, and one consultant representatives (all from Texas) to assess the appropriateness of installing a traffic signal due to pedestrian concerns at five locations. The goal of the effort was to include the possibility of any and all criteria as being part of the pedestrian signal warrant. Most of the responses, however, were focused on the *MUTCD* pedestrian signal warrant criteria and few variations resulted. The research team for this study suggested that these findings were the result of the current methodology being so ingrained in the profession's signal warrant analysis activities rather than indicating that the current pedestrian signal warrant was appropriate. They also noted that the participants' comments indicated a need for additional guidelines on pedestrian crossing treatments.

CURRENT EFFORT

The Texas study provided interesting findings; however, there was a concern with only using engineers from one state. For the TCRP/NCHRP study, the timing and location of the 2004 Institute of Transportation Engineers (ITE) 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 planned for March 28, 2004, in southern California. ITE worked with Texas Transportation Institute (TTI) to advertise the workshop to attendees of the ITE Spring Conference and to members of the Southern California Section of ITE. The workshop's objective was to obtain opinions on the traffic signal warrants; on how they related to specific locations; and on potential treatments, including signalization, for the selected intersections.

SITE SELECTION

Several cities in southern California were contacted to identify potential sites. The cities were asked to suggest crossing locations that were midblock or at an intersection where (a) there have been requests by members of the public to install traffic signals based on pedestrian needs or (b) where there have been higher than average pedestrian collisions. Two cities, Santa Ana and Anaheim, provided several locations. These locations were visited by a member of the research team to determine their appropriateness for inclusion in the study. The sites needed to have sufficient pedestrian activity, needed to not currently have a traffic signal, and needed to be within a reasonable driving distance of the conference hotel. Four locations within each city were included in the workshop. After site selection, the following information was gathered at the eight sites:

- Roadway characteristics (e.g., number of lanes, distance to transit stop, etc.),
- Photographs of existing conditions, and
- Pedestrian and traffic data (hourly basis).

WORKSHOP

The Signal Warrant Engineering Judgment Evaluation Workshop was held on March 28, 2004, just prior to the ITE Spring Meeting. Two tours were conducted as part of the workshop. In the first tour seven engineers participated, while six participated in the second workshop. Each tour included an engineer who was very familiar with the area and was able to answer questions regarding local practices. Of the 13 participants, the regional representation included: 9 west coast, 1 northwest, 1 east coast, and 2 midwest.

Each participant was provided with traffic/pedestrian data, photographs, and a sketch for the eight pedestrian crossing locations. Figure I-1 shows examples of the photographs provided for Site 7. The traffic volumes were provided both in numeric format and plotted on a chart with the relevant curves for Signal Warrant 2 (4-hr vehicular volume) and Warrant 3 (peak hour). Figure I-2 illustrates the chart provided for Site 7. 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. Table I-1 summarizes the data provided on intersection characteristics and results from warrant analysis for the eight sites.

Pedestrian Looking East from North Side

Southbound

Eastbound

Northbound

Figure I-1. Photographs of Site 7.

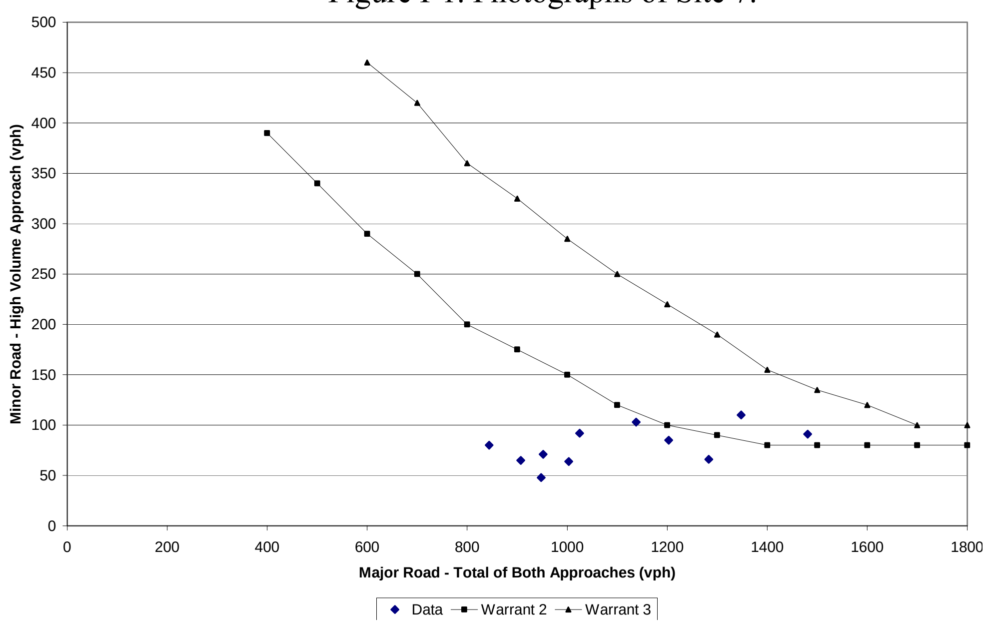


Figure I-2. Warrant 2 and 3 Plot for Site 7.

The group then drove to each site and reviewed the site in the field. While in the field, the participants completed a questionnaire (see Figure I-3). After visiting the eight sites, the tour concluded at the original hotel with a 1-hr discussion. Items covered during the discussion included comments on specific sites along with general discussion on the pedestrian signal warrant. The participants were also asked to complete a general questionnaire on the pedestrian signal warrant (see Figure I-4).

TABLE I-1. Intersection Characteristics and Warrant Analysis Results.

Element	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Number of lanes on major	2	2	2	2	2	2	2	2
Number of lanes on minor	1	1	1	1	1	1	1	1
Critical speed of major road (posted speed limit, mph)	30	35	35	45	40	35	35	35
Distance to the east of nearest signal (ft)	1735	1300	1450	1600	1320	1030	650	1100
Distance to the west of nearest signal (ft)	860	1500	1130	950	1320	1600	475	1500
Distance to cross street (crosswalk length) (ft)	75	64	66	74	92	64	71	56
Calculated gap needed to cross street based on 4 fps + 3 sec startup time (sec)	22	19	20	22	26	19	21	17
Calculated gap needed to cross street based on 3 fps + 3 sec startup time (sec)	28	24	25	28	34	24	27	22
Number of crashes susceptible to correction in past 12 months	0	2	0	1	unk	unk	unk	0
School crosswalk? (Yes or No)	yes	yes	yes	yes	yes	yes	no	yes
Warrant Analysis Result*								
1A, 8-hr vehicular volume	no	no	no	no	no	no	no	no
1B, 8-hr vehicular volume	no	no	no	no	yes	no	no	no
1A&B (80%), 8-hr vehicular volume	no	no	no	no	no	no	no	no
2, 4-hr vehicular volume	no	no	no	no	yes	no	no	no
3, peak hour	no	no	no	no	yes	no	no	no
4, pedestrian volume	no	no	no	no	no	no	may	no
4, pedestrian volume (reduced due to slower walking speed)	NA	NA	likely	NA	NA	yes	NA	NA
5, school crossing	may	no	likely	likely	likely	likely	no	no
6, coordinated signal system	may	may	may	may	may	may	may	may
7, crash experience	no	no	no	no	unk	unk	unk	no
8, roadway network	no	may	may	may	may	may	may	no

*abbreviations:
unk = unknown due to unavailable data
NA = not applicable
may = may meet warrant

TCRP/NCHRP: Improving Pedestrian Safety at Unsignalized Roadway Crossings
Pedestrian Crossing Workshop, Site Reviews
California, March 2004

Site:______________________________ Reviewer:_____________________________

Using the data provided, observations made during your site visit, and your expert opinion, do you think a traffic signal should be installed here (please disregard the warrant analysis results when making this decision)?

❑ Yes ❑ No

Please provide the reasons and/or factors that influenced your decision.__________________
____
____

Attached are preliminary results from a signal warrant analysis. Do you agree with the results that a signal is (or is not) warranted based on the **Pedestrian** Traffic Signal Warrant?

❑ Yes ❑ No

Do you agree with the results for the other warrants?

❑ Yes ❑ No

Please explain why for the above two questions. What factors affected your decision? Should other factors be considered when working with the signal warrants?______________________
____
____

Is a form of less restrictive traffic control needed here?

❑ Yes ❑ No

What traffic control devices would you suggest?_______________________________________
____
____

Please provide the reasons and/or factors that influenced your decision on the less restrictive traffic control.____
____
____

Other comments or observations on the site:____
____
____

Figure I-3. Site Questionnaire.

TCRP/NCHRP: Improving Pedestrian Safety at Unsignalized Roadway Crossings
Pedestrian Crossing Workshop, Wrap-up Questions
California, March 2004

Reviewer: ____________________________

Which factors played the biggest role in your treatment suggestions for the eight sites (select top three):

❑ Traffic Volume ❑ Pedestrian Volume
❑ Presence Of School ❑ Vehicle Gaps Available
❑ Average Crossing Speed Of Pedestrians (Assumed)
❑ Distance To Nearest Signal ❑ Intersection Vs. Midblock
❑ Speed (Operating Or Posted) On Major ❑ Number Of Lanes On Major
❑ Number Of Lanes On Minor ❑ Nearby Lane Uses
❑ Crash History ❑ Presence Of Median On Major
Other: _________________________

Currently the *MUTCD* considers the following factors in the Pedestrian Signal Warrant: pedestrian volume, gaps, distance to nearest signal, and average crossing speed of pedestrian. What other factors do you think should be included in a revised signal warrant?_____________________________________

Do you think the *MUTCD* should include warrants for less restrictive traffic control devices (i.e., warning flashers, in-pavement lights, etc.) at uncontrolled pedestrian crossings?

❑ Yes ❑ No

What factors do you think should be included in a warrant or guidelines for other types of pedestrian treatments (e.g., in-roadway warning lights, etc.)? ____

Should **guidelines** for less restrictive control reflect a percentage of the signal warrant criteria (e.g., consider in-roadway lights when ped volume is 50% of signal warrant)?

❑ Yes ❑ No

What percent of the pedestrian signal warrant would you think appropriate for guidelines on when to install….:

static signs and markings _____________
yellow flashing devices ______________
red flashing devices ______________

Approximately how many signals does your jurisdiction maintain? _________________________________

A suggestion has been made to revise the pedestrian volume in the pedestrian signal warrant from 190 ped/h in the peak hour to 75 ped/h (or 60 ped/h for any 4 hours). If the pedestrian signal warrant was modified to reflect lower pedestrian volumes, please give your best estimate of how many additional signals would likely be installed in your jurisdiction (number or percent):____________________________

Do you think this is too many?

❑ Yes ❑ No

Please provide the reasons that influenced your above response._________________________________

If traffic signals could be installed based on your engineering judgment of pedestrian needs, as you have used during the site evaluations today, approximately how many additional signals would be installed in your jurisdiction? ____

Figure I-4. Wrap-Up Questionnaire.

FINDINGS

Site 1

Site 1 has four lanes on the major road and two lanes on the minor road. Major road volumes range between 200 and 700 veh/h. The minor road has less than 100 veh/h. The pedestrian volumes crossing the major street range between 10 and 75 ped/h. In the warrant analysis, only the school crossing warrant may be met at the site. None of the participants supported the consideration of a signal at this location. They emphasized the need to try other alternatives before installing a signal (crossing guard if not already used, flashing beacons that operate either on demand or only during school hours, narrowing crossing distance through curb extensions or median refuge, etc.)

Site 2

Site 2 has four lanes on the major road and two lanes on the minor road. Major road volumes range between 700 and 1700 veh/h. The minor road has less than 100 veh/h. The pedestrian volumes crossing the major street range between 10 and 90 ped/h. In the warrant analysis, only the coordinated signal system or roadway network warrants may be met at the site. The two participants who felt a signal should be considered at this location focused on the large number of pedestrians in the morning peak hour, the traffic speed on the major roadway, the distance to the nearest signal (over 1300 ft [396 m]), and the observation that the crossing guard is frequently ignored. Other treatments suggested for this location include: narrowing roadway, median refuge, curb extensions, repainting of markings, and warning devices.

Site 3

Site 3 has four lanes on the major road and two lanes on the minor road. Major road volumes range between 600 and 1600 veh/h. The minor road has less than 100 veh/h. The pedestrian volumes crossing the major street range between 0 and 130 ped/h. In the warrant analysis, the reduced pedestrian signal warrant was met, while the school crossing, coordinated signal system, or roadway network warrants may be met at the site. The four participants (31 percent) that supported a signal were influenced by the high pedestrian volumes (2 hours had over 80 ped/h), the high vehicle volumes (11 hours were over 600 veh/h on the major), the presence of a school, and the absence of pedestrian refuge. The participants that did not support a signal observed that the cross traffic was very low and that a crossing guard would be a better solution. Treatments suggested included flashing beacon or in-pavement warning lights with passive detection and median refuge.

Site 4

Site 4 has four lanes on the major road and two lanes on the minor road. The major road speed limit is posted at 45 mph (72 km/h) and the width of the street to be crossed is 74 ft (23 m). Major road volumes range between 400 and 900 veh/h. The minor road has less than 100 veh/h. The pedestrian volume crossing the major street has 2 hours where the volume exceeds 50 ped/h and 3 hours where it exceeds 20 ped/h. In the warrant analysis, the school crossing, coordinated signal system, or roadway network warrants may be met at the site. The four participants that supported a signal (31 percent) were influenced by the high pedestrian volumes (2 hours had about 80 ped/h), the presence of a school, the high major road vehicle speeds, and sight obstructions. The participants that did not support a signal observed that the heavy pedestrian use is limited to school hours and that a crossing guard or flashing beacons would be the better solution.

Site 5

Site 5 has four lanes on the major road and two lanes on the minor road. The major road speed limit is posted at 40 mph (64 km/h) and the width of the street to be crossed is 92 ft (28 m). Major road volumes range between 1000 and 2000 veh/h. The minor road has between 50 and 140 veh/h. The pedestrian volume crossing the major street had 5 hours where it exceeds 20 ped/h. In the warrant analysis, the school crossing, coordinated signal system, or roadway network warrants may be met at the site. Warrants 1 (8-hr vehicular volume), 4 (4-hr vehicular volume), and 3 (peak hour) were met at the site. Most of the participants (85 percent) supported the consideration of a signal at this site. The two participants that did not support a signal felt that the pedestrian volumes were low compared to the major street vehicular volumes and that there is adequate warning and markings provided. The rest of the participants felt the high volumes (major road volumes over 1000 veh/h for each of 11 hours), high speeds (40 mph [64 km/h] posted speed limit), and difficult in crossing such a facility supports the consideration of a signal. One participant thought that the pedestrian numbers were low because “it is a scary intersection to cross.”

Site 6

Site 6 has four lanes on the major road and two lanes on the minor road. Major road volumes range between 450 and 1350 veh/h while the minor road volume ranges between 80 and 160 veh/h. The pedestrian volume crossing the major street had 6 hours with more than 20 ped/h, 2 hours with more than 50 ped/h, and 1 hour with more than 100 ped/h. In the warrant analysis, the pedestrian signal warrant was met when the average walking speed was assumed to be less than 4 ft/s (1.22 m/s), while the school crossing, coordinated signal system, or roadway network warrants may be met at the site. The participants were about evenly split between supporting or not supporting a signal. Participants noted that the pattern of pedestrian volumes matched the school hours and therefore, less restrictive controls (e.g., crossing guard or on-demand flashers) should be used prior to a traffic signal. Others felt that the distance to the nearest signal, the presence of 10 to 20 ped/h (present even during nonpeak school hours), high speeds, and long crossing distance support the consideration of a signal. During the traditional school day, the morning and afternoon peaks have between 85 and 102 ped/h. One participant felt that even though the pedestrian signal warrant was not met when average walking speed was greater than 4 ft/s (1.22 m/s), a signal should be considered because the high volumes would result in a difficult crossing for the students.

Site 7

Site 7 has four lanes on the major and two lanes on the minor. Major road volumes range between 850 and 1500 veh/h while the minor road volume ranges between 50 and 110 veh/h. The pedestrian volume crossing the major street had 10 hours with more than 100 ped/h. In the warrant analysis, the pedestrian signal warrant was met, while the coordinated signal system or roadway network warrants may be met at the site. A slight majority of the participants felt that a signal should be considered at this location due to the high number of pedestrians (over 120 ped/h for 10 hours). Others felt that sufficient gaps exist and that drivers are aware of the multiple pedestrian crossings in the area. Several noted that a refuge island should be installed to improve the condition for pedestrians and that if a signal is installed it needs to be coordinated with the nearby signals.

Site 8

Site 8 has four lanes on the major road and two lanes on the minor road. Major road volumes range between 450 and 700 veh/h while the minor road volume ranges between 15 and 50 veh/h. The pedestrian volume crossing the major street had less than 10 ped/h. In the warrant analysis, none of the warrants were met. The low traffic and pedestrian volumes factored into the participants unanimously agreeing that a signal should not be considered at this location. Several participants noted that this location may be a candidate for a "road diet." The four-lane undivided facility may perform better being restriped to include two through lanes, a two-way left-turn lane, and a pedestrian refuge area at the intersection.

Follow-On Discussion

After the participants visited the eight sites, they met to complete the surveys and to provide observations and discussion. When asked which factors played the biggest role in their treatment suggestions for the eight sites, they responded with the following (the percentage value shown in parentheses represent the number of responses divided by 13, for example, 12 of the 13 participants selected pedestrian volume):

- Pedestrian volume (92 percent),
- Traffic volume (77 percent),
- Speed (operating or posted) on major (46 percent),
- Number of lanes on major (23 percent),
- Other: opportunity for median refuge, crossing distance, 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).

The participants listed the following when asked what factors that are not currently included in the *MUTCD* should be considered in a pedestrian signal warrant (the *MUTCD* currently includes pedestrian volume, gaps, distance to nearest signal, average crossing speed of pedestrian):

- Operating speed,
- Crossing distance/width of street ,
- Presence of refuge islands,
- Sight distance (including the effects of on-street parking),
- Combination of pedestrian and vehicle volumes, perhaps with different level of criteria during non-peak school crossing times, and
- Crash history.

Also explored during the discussion was whether the *MUTCD* should include warrants for less restrictive traffic control devices (e.g., warning flashers, in-pavement lights, etc.). Most of the participants said that the *MUTCD* should include warrants (8 of the 13 participants); however, they noted that the preference is to include "guidelines" rather than "warrants." They would also like information on the effectiveness of the devices. When asked if the guidelines for less restrictive control reflect a percentage of the signal warrant criteria what should that percentage be, the participants responded with values between 25 and 75 percent. In other words, the participants felt that a yellow flashing beacon should be considered at about 50 percent of the volumes being used to warrant a traffic signal.

For those responsible for a signal system, they were asked to estimate how many additional signals would be warranted if the peak hour in the pedestrian signal warrant was reduced from 190 to 75 ped/h. The estimates ranged from 2 to 20 percent. Five of the seven participants who have responsibility for a signal system indicated that they did not think this was too many additional signals. Reasons for their answers included: "we need to provide better pedestrian access on arterials," "pedestrian safety should be just as important as vehicle safety," and "not sure if warranting pedestrian signals with lower volumes will decrease or increase safety versus more warning devices that are passively activated (and that are cheaper)."

CONCLUSIONS

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 engineer's judgment toward the traffic signal warrants (or toward proposed revisions to the traffic signal warrants) are needed. The Signal Warrant Engineering Judgment Evaluation Workshop was held on March 28, 2004, just prior to the ITE Spring Meeting. Two tours were conducted as part of the workshop. In the first tour seven engineers participated, while six participated in the second workshop. Of the 13 participants, the regional representation included: 9 west coast, 1 northwest, 1 east coast, and 2 midwest. Observations from the Workshop include the following:

- **The revised pedestrian signal warrant should include consideration of the width of roadway being crossed.** The width could either be number of lanes or width of roadway; however, if 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 (since 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 <u>along with</u> 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 (example given was at a site where there 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 comments from the participants indicated a preference to 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 made comments with respect to equally treating pedestrians and vehicles.
- 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 that is stopped in the near lane, but 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 multilane 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 (46 percent),
  - Number of lanes on major (23 percent),
  - Other: opportunity for median refuge, crossing distance, 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* that are not currently present the only factor they listed 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.

APPENDIX J

SURVEY OF PROVIDERS

METHODOLOGY

Several survey techniques were used to obtain information on pedestrian treatments and on the challenges of identifying and providing pedestrian treatments. These techniques included the following:

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

Typical questions used for the focus groups of the providers and the on-site interviews are listed in Table J-1. Following is a summary of the methods used and the findings by survey.

FOCUS GROUPS OF PROVIDERS

The research team conducted two focus group sessions to discuss intersection and midblock treatment preferences. The focus group sessions occurred in Ft. Lauderdale, Florida, prior to the ITE Spring Meeting, which allowed participants from a range of geographical locations to be present.

An initial invitation was distributed to all ITE members who were members of the Traffic Engineering, Transit, or the Pedestrian & Bicycle Council in early February 2003. A supplemental invitation was distributed in March 2003 to those ITE members who were local (i.e., are more likely to attend because the driving time is minimal) and work for a transit agency, city, or county but had not already received an invitation. We wanted to add a few more participants so that we would have a higher percentage of local government representation during the focus group sessions.

The two focus groups were held on March 23, 2003, in Ft. Lauderdale, Florida. One was from 4 to 6 p.m. and the other from 7 to 9 p.m. The 4 to 6 p.m. focus group included six in attendance plus the two research team members, while the 7 to 9 p.m. focus group included eight participants along with the two research team members. Participant's employer types are listed in Table J-2, with local government having the greatest representation of the groups (8 of 14 members had worked for a local government). The homes of the participants ranged from Florida to Washington D.C. to the west coast with nine being from the east coast, one from a central state, and four from the west coast. Their work experience with pedestrian treatments ranged from 10 to 40 years. Two of the participants were blind and provided insight into pedestrian treatments from the point of view of not being able to see them.

TABLE J-1. Typical Questions Used in Focus Groups of Providers and On-Site Interviews.

Treatments Used at Unsignalized Intersections

- What is your preferred pedestrian treatment(s) for unsignalized intersections? Do you consider it very effective? If so, by what criteria? Are the treatments well liked? Other reasons for using it?
- What other treatments have you used at unsignalized? Are they effective? What is limiting their use?
- How do you decide which treatment to use at a crossing?

Treatments Used at Midblock Locations

- What is your preferred pedestrian treatment(s) for midblock locations? Do you consider it very effective? Well liked? Other reasons for using it?
- What other treatments have you used at midblock locations? Are they effective? Are they costly? What is limiting their use?
- How do you decide which treatment to use at a crossing?
- Are your decisions affected by the presence of a bus stop?

Program for Pedestrian Treatments

- When do you consider installing a pedestrian crossing treatment at an unsignalized intersection? (complaints, ADT, existing crosswalk, crashes, etc.)
- What studies or research are used to determine the type of pedestrian treatment? (speed, vehicle volume, pedestrian volume, neighboring developments, type of pedestrian [old, young, disabled])
- Who do you typically work with when addressing a pedestrian concern (residents, businesses, transit agencies, planners, community economic development, Public Works, other professionals, etc.)

Signals at Midblock Locations

- What are your thoughts regarding the use of signals at midblock crossings?
- When are they appropriate (or not appropriate)?
- Do you use supplemental signing for a midblock crossing?
- When should midblock signals be considered?
- What other treatments are typically considered or used before using a midblock signal?

Signal Warrants

- Do you have specific concerns regarding the pedestrian warrants? (e.g., ped volumes too high, gap criteria too difficult to measure, no regard for vehicle speed or roadway classification, no regard for safety, etc.)
- What criteria do you think should be addressed in a signal warrant that considers pedestrians? (e.g., gaps, pedestrian volume, vehicle speed, vehicle volume, etc.)
- Should the criteria used in a signal warrant that consider pedestrian also include a reduction factors for when speeds are in excess of 40 mph (64 km/h)? Are there other conditions where a reduction factor should be considered?
- What if the traditional "vehicular-based volume" signal warrants, which are clearly designed for unsignalized intersections, included both pedestrians and bicyclists in the minor street approach count? (There is a new statement in the manual that allows bicyclists to be counted.) This minor change to the signal warrants would cover the unsignalized intersections and allow for the pedestrian warrant to focus exclusively at midblock locations.
- Should a new pedestrian signal warrant consider a presence of a bus stop? If so, how should the bus stop be considered (presence, distance to nearest existing crossing, pedestrian volumes in peak periods, etc.)

TABLE J-2. Focus Group Participants.

Number of Participants	Employer
1	State
5	Local Government
3	Mix of Local Government and Consultant Experience
4	Consultant
1	Federal Agency
14	**Total Participants**

A pre-survey was distributed to the participants as they entered the room. This provided an opportunity for the participants to begin thinking of the issues that would be discussed and to provide the research team with the full name and address of the participant. A question on the survey requested the participant's preference for treatments at unsignalized intersections and at midblock crossings. The participants could check more than one treatment. Their responses are shown in Figures J-1 and J-2 for unsignalized and midblock crossings, respectively. Refuge islands and high-visibility markings received the highest preference with over 70 percent. Roadway pedestrian signing also received over 70 percent for midblock location only.

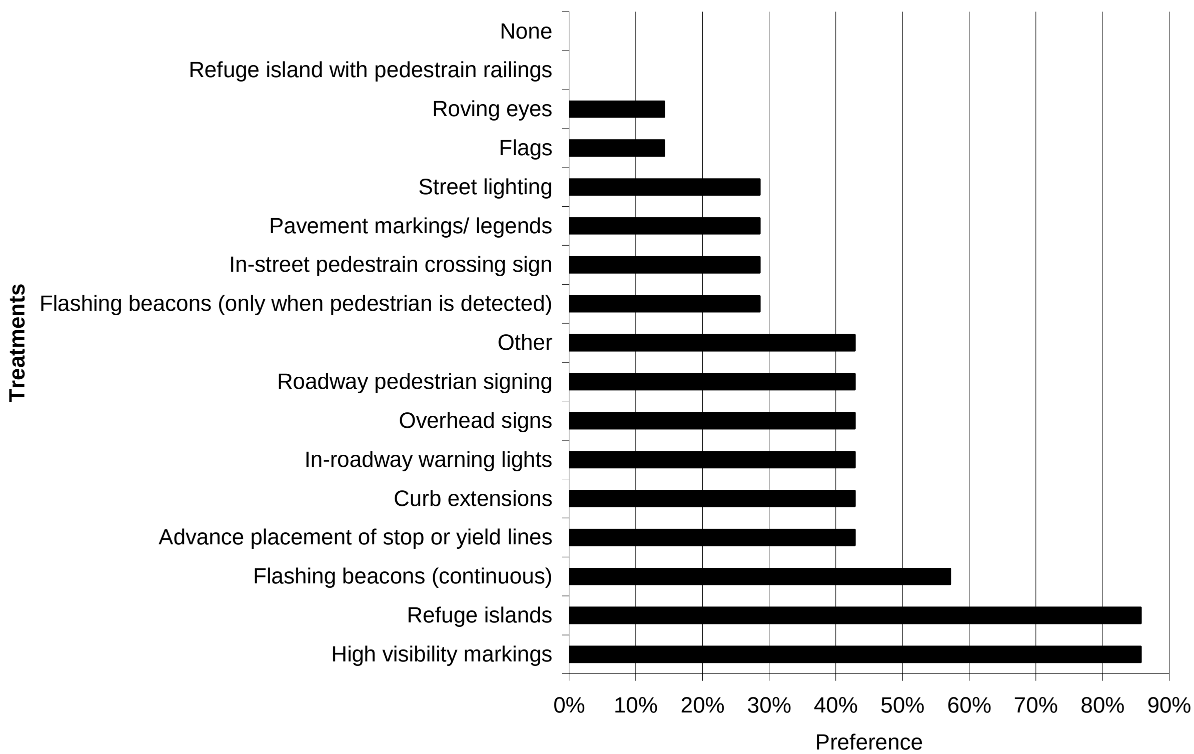


Figure J-1. Preference of Focus Group Participants for Pedestrian Crossing Treatments at Unsignalized Intersections.

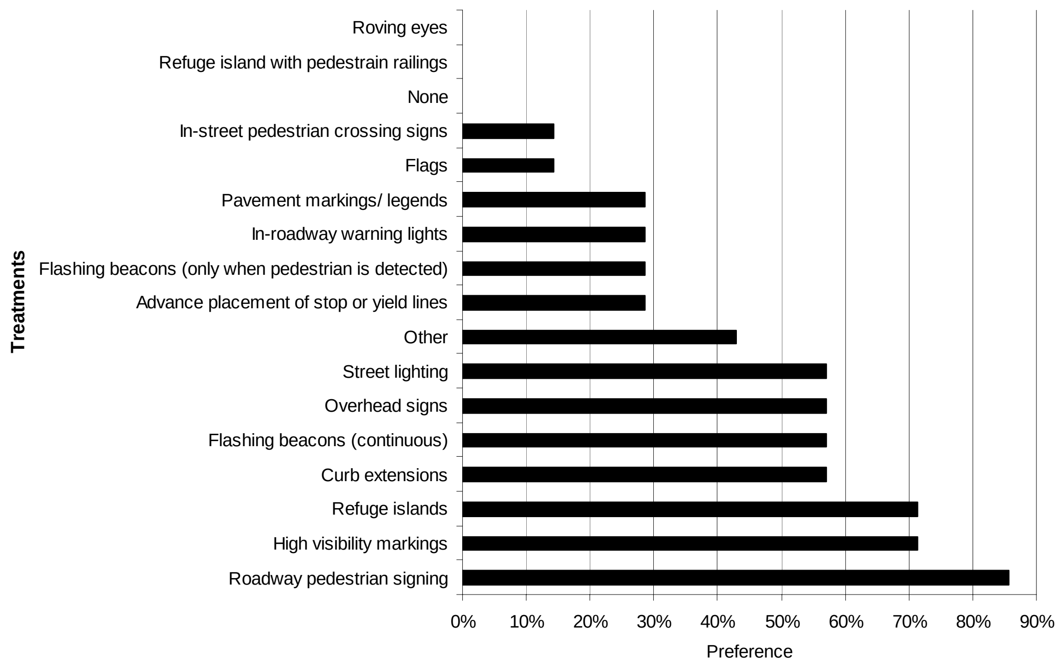


Figure J-2. Preference of Focus Group Participants for Pedestrian Crossing Treatments at Midblock Locations.

Key Findings

The questions developed for use in the focus group are listed in Table J-1. The questions actually used depended upon how the discussions proceeded during the focus group. If the group had greater interest in discussing treatments as opposed to signal warrants, then greater time was spent on the treatment questions. Following are the key findings from the focus groups by major discussion area.

Treatments Used at Unsignalized Intersections

- Several treatments were mentioned including high-visibility markings, bulb outs, refuge islands, and others.
- Participants indicated the following:
  - Continuous flashing beacons have less than desired impact on driver behavior.
  - Pedestrians have a reluctance to use the pedestrian flags; however, they are an unusual treatment which is positive.
  - Should the profession consider a sign that says “flashing when pedestrian is present” to indicate that the flashing beacon is only active due the presence of a pedestrian?
  - Landscaping or other guidance strips could help direct the pedestrian across the curb extension. Participant noted that pyramids or large pebbles embedded in the concrete are used in Europe.
- The blind pedestrian needs guidance on when a treatment is activated (e.g., lights at an in-roadway warning light installation). Valuable crossing time is lost when the pedestrian is trying to determine if the treatment is active. A tone would also help

inattentive sighted pedestrians know when the treatment is activated. Blind pedestrians also need a location device to know where to activate the treatment.
- Several participants commented on the in-street pedestrian crossing signs. This is a relatively new treatment that has caught the attention of several communities. There is a desire to know more about their effectiveness. One participant felt they are more effective with a regulatory message than a warning message. Concerns were expressed over whether pedestrians would trip over the sign.

Treatments Used at Midblock Locations

- Characteristics of a preferred midblock crossing include: median refuge area if on a multilane facility (especially when high speeds or high volumes are present), curb extensions, and advance warning system that is activated by a pedestrian. Another treatment mentioned for midblock crossings was the in-roadway warning lights.
- For blind users, an indication that the crossing is present is really important. One suggestion is to use changes in pavement surface to indicate the presence of a midblock crossing. Corners are not available to assist in locating the crossing.
- Bus stops have been considered in selecting a treatment at a midblock location; however, it was noted that it should be one of several factors to be considered. Other factors include intersection spacing, land use (that creates the demand), pedestrian characteristics (e.g., senior citizens), schools, churches, presence of sidewalks, and distance of generator to next signalized intersection.

Program for Pedestrian Treatments

- Issues considered when selecting pedestrian treatments include: roadway volumes (major versus minor street), turning movement volumes, pedestrian characteristics at the site, available right-of-way, and crashes.

Signals at Midblock Locations

- The profession needs to investigate techniques that minimize delay to motorists while giving pedestrians access to cross the street so as to minimize the impacts of signals at midblock locations.
- Need a quick response to the pedestrian activation to encourage its use.
- Consider two-stage crossing so that a midblock signal can be split and coordinated with upstream signals.
- Preference is to use supplemental signing at a midblock crossing. The sign, however, can block the view of the pedestrian, so placement is critical. Consider using an activated device because a sign is frequently ignored by drivers. Good to have signs that remind the motorists that they need to yield to pedestrians in crosswalks.
- Treatments used prior to installing a midblock signal include: pedestrian flags, in-roadway warning lights, advance warning, pavement markings, curb extension, and lighting.

Signal Warrants

- The participants felt that the signal warrant is too geared to vehicles and that it only considers existing pedestrians and not what could be present if a signal was installed.
- The warrant should include reduction factors for operating speed on roadway, absence of median, and number of lanes.
- Several participants noted that the warrant should consider nearby pedestrian generators (which could include a bus stop).
- One participant noted that the system warrant was used to justify signals to achieve a 28 mph (45 km/h) operating speed. This resulted in platoons along the corridor that made it easier for pedestrians to cross at other locations.
- Suggestions for improvement include the following:
  - consideration of land use (type of generator),
  - consideration of sidewalk network and is it a key bike/pedestrian link,
  - characteristics of pedestrians (number of older, very young, disabled, and blind users),
  - geometrics at the site (number of lanes, presence of median),
  - proximity of other crossings, and
  - sensitivity to the type of signal technology that would be used (if the device will have minimal impact on operations, then it should be easier to warrant).

PHONE MEETINGS

Several agencies were contacted early in the project to identify potential pedestrian treatments and to identify which regions should be visited as part of the on-site interviews. These contacts also provided insight into how treatments are selected. Table J-3 lists the agencies contacted by phone.

TABLE J-3. Cities and Agencies Contacted.

Cities or Agencies	
Atlanta, GA	Redmond, WA
Austin, TX	Salem, OR
Bellevue, WA	Salt Lake City, UT
College Station, TX	San Antonio, TX Metropolitan Planning Organization
Dallas, TX	San Diego, CA
FHWA	San Francisco, CA
Florida DOT	San Jose, CA
Irving, TX	Seattle, WA
Kirkland, WA	Spokane, WA MPO
Lane Transit District (Eugene, OR)	Texas DOT
Las Vegas, NV	TriMet Transit (Portland, OR)
Los Angeles, CA	Tucson, AZ
Montgomery County, MD	Vancouver, WA
Portland, OR	Washington State DOT

ON-SITE INTERVIEWS

On-site interviews were conducted in several cities. During those interviews the research team met with numerous city and state transportation departments and transit agencies on their practices regarding pedestrian crossing treatments, use of traffic signal warrants, and transit stop provisions along major arterial streets. Table J-4 lists the agencies that were involved in these interviews. Table J-1 contains the list of questions that were used to guide the discussions with these agency representatives. In addition to the meetings, the research team visited sites with pedestrian treatments. Following is a brief overview on pedestrian treatments observed during some of the site visits and general comments made during the interviews.

TABLE J-4. Agency Interviews.

Date and Location of Interview	Agency	Representatives
March 12, 2003 Salt Lake City, Utah	City of Salt Lake, Utah	Dan Bergenthal, P.E.
April 7, 2003 Tucson, Arizona	City of Tucson, Arizona	Richard Nassi, Ph.D., P.E. Shellie Ginn
	Sun Tran	George Caria
April 8, 2003 Phoenix, Arizona	City of Phoenix, Arizona – Street Transportation Dept.	Michael Cynecki, P.E. Thomas Godbee, P.E. Ron Robinson
	City of Phoenix, Arizona – Public Transit Dept.	Chuck Italiano
April 9, 2003 Santa Monica, California	City of Santa Monica, California	Lucy Dyke, P.E. Beth Rolandson
April 10, 2003 Los Angeles, California	City of Los Angeles, California	Wayne Tanda, P.E. John Fisher, P.E.
June 2, 2003 Seattle area and Olympia, Washington	Washington State DOT	Julie Mercer-Matlick Paula Reeves
	City of University Place, Washington	Pat O'Neill, P.E.
	City of Olympia, Washington	Randy Wesselman, P.E.
June 3, 2003 Seattle, Washington	City of Seattle, Washington	Robert Spillar, P.E. Brian Kemper, P.E. Megan Hoyt
	King County METRO	Ross Hudson
June 4, 2003 Kirkland, Washington	City of Kirkland, Washington	David Godfrey, P.E.
	City of Bellevue, Washington	Mark Poch, P.E., P.T.O.E. Kurt Latt, P.E., P.T.O.E.
	City of Redmond, Washington	Jeff Palmer, P.E. Susan Byszeski
June 5, 2003 Portland, Oregon	City of Portland, Oregon	Bill Kloos, P.E. Jamie Jeffreys, P.E. Jean Senechal, A.S.L.A.
	Oregon DOT	Basil Christopher, P.E.

Portland, Oregon

Typical treatments used in Portland include intersection pedestrian signals (also known as half-signals) and pedestrian median refuge islands. Other treatments that have been installed are in-roadway warning lights and overhead or side beacons activated by passive detection. Figure J-3a is an example of a pedestrian signal with advance stop bar and STOP HERE ON RED sign. Figure J-3b is an example of a pedestrian median refuge island, and Figure J-3c is an example of an intersection pedestrian signal (half-signal). Comments made during the meeting with agency representatives are:

- Intersection pedestrian signals (half-signals) were installed many years previously (over 15 years); however, have not installed any recently.
- Suggested that if the intersection pedestrian signals were to be installed elsewhere to use them where there are light traffic volumes on the side street and there is a reasonable distance to a signalized intersection.
- Benefits of intersection pedestrian signals include that they do not attract additional side street volume since the control on the side street is a STOP sign rather than a signal indication.
- Oregon will now have a law which requires drivers to stop and remain stopped until the pedestrian either reaches the other side of the street or is at least one lane away from the car in a multilane street. The bill was signed into law on June 17, 2003, and goes into effect January 1, 2004.

(a) Pedestrian Signal with Advance Stop Bar

(b) Pedestrian Median Refuge Island

(c) (Half-Signal)

Figure J-3. Examples of Treatments in Portland.

Kirkland, Washington

Typical treatments used in Kirkland include pedestrian flags and pedestrian median refuge islands. Other treatments that have been installed are in-roadway warning lights and midblock pedestrian signals. Figure J-4a is an example of the instructions for the flag treatment (see Figure J-4b). Figure J-4c is an example of pedestrian median refuge island. Comments made during the meeting with agency representatives are:

- Pedestrian median refuge islands are important as a first step for sites needing a pedestrian treatment (along with median curb extensions).
- They have had positive experience with pedestrian flags and have them at about 20 locations in the city. The city maintains those in the downtown area and is willing to install in other locations if the community is willing to restock the flags as needed.
- Many pedestrians like the in-pavement warning lights; however, complaints about drivers not stopping for the pedestrians are still received.

(a) Instructions for Pedestrian Flags


(b) Pedestrian Flags and Crossing Signs


(c) Overhead Signs, Pedestrian Refuge Island at Marked Crosswalk

Figure J-4. Example of Treatments in Kirkland.

Redmond, Washington

Typical treatments used in Redmond include in-street pedestrian crossing signs, which are being evaluated at nine locations. Other treatments that have been installed are in-roadway warning lights, midblock pedestrian signal (recent installation at Microsoft), and intersection pedestrian signals. Figure J-5a is an example of a midblock pedestrian signal, and Figure J-5b is an example of a marked crossing where in-roadway warning lights will be installed. Figure J-5c and J-5d are examples of crossing signals; Figure J-5c is an in-street pedestrian crossing sign, and Figure J-5d is a roadside pedestrian crossing sign. Comments made during the meeting with agency representatives are:

General comment

- Have proposed criteria for (a) in-roadway warning lights at crosswalks and (b) signals.

In-street pedestrian crossing signs

- Are currently 6 months into a 12-month evaluation.
- Started with 14 sites; about 9 sites are currently in the study (lost some due to construction trucks).
- Installed on sites with three travel lanes or less and speeds of 30 mph (48 km/h) or less.
- Acceptance by drivers is increasing with familiarity with the signs.

(a) New Midblock Pedestrian Signal at Microsoft

(b) Marked Crosswalk

(c) In-Street Pedestrian Crossing Sign

(d) Pedestrian Crossing Sign

Figure J-5. Examples of Treatments in Redmond.

Bellveue, Washington

Typical treatments used in Bellveue include pedestrian median refuge island at midblock crossings, overhead signing, lighting at crosswalk, and variable speed limit in school zones. Other treatments that have been installed are in-roadway warning lights, midblock pedestrian signals, and a split midblock pedestrian signal treatment. Figure J-6a is an example of a split midblock pedestrian signal, and Figure J-6b is an example of an overhead sign and median pedestrian refuge island at a marked crosswalk. Comments made during the meeting with agency representatives are:

- Had questions on using bulb outs with bike lanes.
- Will be using the advance stop bar because of concerns with multiple-threat problem.
- Encourage the location of bus stop at signals.

(a) Split Midblock Pedestrian Signal

(b) Overhead Sign and Pedestrian Median Refuge Island at a Marked Crosswalk

Figure J-6. Examples of Treatments in Bellevue.

Seattle, Washington

Typical treatments used in Seattle include intersection pedestrian signals (about 70 locations) and median pedestrian refuge islands. Other treatments that have been installed are in-roadway warning lights and overhead crosswalk signs with flashers. Figure J-7 is an example of an intersection pedestrian signal. Comments made during the meeting with agency representatives follow:

General comments

- Seattle has intersection pedestrian signal (commonly called half-signals) criteria which state that pedestrian volumes can be increased if information indicates that an immediate increase in actual pedestrian volume can be anticipated due to the installation of the treatment.
- They recently conducted an inventory of their crosswalks. Will be reviewing by corridor and will consider school, bus stop, major generator locations, etc., when deciding whether to remove, consolidate, or install marked crossings.

- City is focused on providing a pedestrian-friendly environment that includes traffic calming, sidewalks, etc., that is also balanced with traffic needs.
- Encourage enforcement and education to take place before increasing the level of control at a location. Sometimes the concern can be addressed with additional enforcement or education.

Intersection Pedestrian Signal (Half-Signal)

- In-house data on intersection pedestrian signals show that they provide a safety benefit to both pedestrians and motorists.
- At the intersection pedestrian signal, the stop bar is 40 ft (12.2 m) from the crosswalk. Only one crosswalk across the major road is marked.
- The signal dwells in green, then goes to yellow, and then red. Usually gives 6 to 7 seconds of walk and then clearance based on walking speed and width.

Figure J-7. Example of an Intersection Pedestrian Signal in Seattle.

Los Angeles, California

Typical treatments used in Los Angeles include Smart Pedestrian Warnings and midblock pedestrian signals. Another treatment used in the area is to have trained staff available for traffic control at special events. Figure J-8a is an example of midblock pedestrian signal, H-8b is an example of a Smart Pedestrian Warning treatment, and H-8c is an example of the use of the yellow color for crosswalks near a school. Comments made during the meeting with agency representatives include:

General comments

- Have criteria for: marking crosswalks, Smart Pedestrian Warnings, signals at intersections, and signals at midblock.
- Have educational program for school children. Attempt to visit each school every other year to educate how to get to school safely.
- Pavement markings for crossings near schools (within 600 ft [183 m]) are yellow.
- A pedestrian advisory group provides input on the selection of pedestrian treatments.
- Pedestrian safety is not just engineering, it also needs education and enforcement. Will be developing an education campaign on pedestrian safety.

Smart Pedestrian Warnings

- Is used as a measure when more control is needed, and the site does not meet signal warrant.
- Selection of sites is based on a point system developed by the city.
- Developed in 1998 and have installed about 15 to date.

Midblock Pedestrian Signals

- Dwell in green arrow, are pedestrian activated (push button), and can be coordinated with other signals.

(a) Midblock Pedestrian Signal

(b) Smart Pedestrian Warning

(c) Marked Crosswalk near a School

Figure J-8. Examples of Treatments in Los Angeles.

Phoenix, Arizona

A typical treatment used in Phoenix is the fluorescent yellow-green color at school crossings. Other treatments that have been installed are flashers and rumble strips. Figure J-9 is an example of flashers and fluorescent yellow-green at school crossings. Comments made during the meeting with agency representatives include:

- A major change for the city is light rail (start construction in 2004 and start service in 2006). Pedestrians will cross at signalized intersections (located every 0.25 mi [0.4 km] outside of downtown, every block in downtown). Signals will have a countdown indication.

Figure J-9. Example of Treatments Used near a Phoenix School.

Tucson, Arizona

Typical treatments used in Tucson include the HAWK and the split midblock pedestrian signal. These treatments frequently include countdown signal indications. Figure J-10a and J-10b are examples of instructions, while Figure J-10c and J-10d are examples of the HAWK treatment. Comments made during the meeting with agency representatives are:

General comments

- Mobility expert groups provide the city input on pedestrian treatments.
- Citizens are asking for midblock median cuts at unmarked crossings.
- Are using pedestrian median refuge islands to decrease crossing exposure at large intersections.

HAWK

- Have installed about 15 to 20 HAWKs.
- Usually not installed within 0.25 mi (0.4 km) of another signal. Transit spacing is also at 0.25 mi (0.4 km).

- Are educating drivers about the difference between solid red (stop) and flashing red (stop and go).
- Are changing the display over time to address concerns.

(a) Sign use at a HAWK Crossing

(b) Instruction Sign at a Crossing


(c) HAWK


(d) HAWK

Figure J-10. Examples of Treatments in Tucson.

FOCUS GROUP OF BUS DRIVERS

In order to obtain transit driver opinions on the behavior of transit patrons as they approach or walk away from the transit vehicle, TTI researchers conducted a discussion group with Sun Tran transit driver personnel in Tucson, Arizona. The discussion group was held on Wednesday, May 21, 2003, at the Sun Tran Station and lasted approximately 1 hour.

Methodology

The discussion group consisted of five sections: (a) Pre-discussion group survey, (b) Introductions, (c) Pedestrian hazards, (d) Handicapped pedestrian hazards, and (e) Closing suggestions.

Pre-Discussion Group Survey

To obtain background information and to help stimulate the group's thinking on transit patron behaviors, a short survey was distributed as the participants arrived and was completed before the discussion group began. Table J-5 contains a summary of the survey responses.

TABLE J-5. Participant Information.

Part. #	Years Driving		Pedestrian Walks Inappropriately		Percent of Pedestrians That Do Not Use Enough Caution	
	Motor Vehicle	Bus	in Front of Bus	Behind Bus	Approaching Bus	Walking away from Bus
1	45	6	Always	Very often	26-50	51-75
2	27	8	Very often	Very often	26-50	26-50
3	42	4	Fairly often	Fairly often	26-50	51-75
4	30	11	Always	Very often	51-75	26-50
5	38	14	Fairly often	Fairly often	26-50	26-50

Table J-5 shows that there were five Sun Tran transit drivers that attended the discussion group. The time that they have been driving a bus varied from 6 to 14 years. When asked how often did pedestrians inappropriately walk in front of or behind their transit vehicle each day, two individuals felt that they "always" walked in front of their transit vehicle inappropriately and "very often" walked inappropriately behind their transit vehicle. The remaining three members of the group found no difference between those pedestrians that walk in the front or behind the transit vehicle inappropriately (one responding "very often" and two "fairly often") for either situation.

Introductions

Introductions were made to build rapport, establish the sense of a group, and to help the group to focus on the topic. With this in mind, the moderator asked each participant to state their first name and share with the group the number one hazard (or closest call) they had experienced with pedestrians while driving a transit vehicle.

All of the participants in the group had experienced a hazard (or close call) with pedestrians walking in front of their transit vehicle while driving. Two members of the group explained that their incident was caused when a pedestrian forgot his/her bike on the transit vehicle rack and jumped in front of the transit vehicle to retrieve it as the transit vehicle was pulling away. The remaining three participants had close calls when a pedestrian suddenly darted in front of the transit vehicle from their blind side (the driver's left side).

As a follow-up question the group was then asked "*Do any of you have any suggestions that would improve the safety for any of the hazards mentioned?*" The following responses were made:

- Give the public free seminars on how to ride a transit vehicle safely.
- Remind the patron that the bike belongs to them and is therefore their responsibility in loading and unloading from the transit vehicle.
- Place a sticker on the front of the transit vehicle near the transit vehicle rack reminding passengers to inform the transit driver that they have a bike on the transit vehicle rack.

Questions

Based on the initial one-on-one survey responses that were collected in Texas and Florida, questions were developed for use during the discussion group. These questions are as following:

Pedestrian Hazards

- *"Question 1. What is the most significant safety problem you have observed with pedestrians as they are approaching or walking away from the bus? How do you handle the situation?*

- *Question 2. Do you have any suggestions on how to solve the problems you have observed?*

- *Question 3. Do you feel like any of these problems could be solved by different pedestrian crossing designs? If so, explain.*

- *Question 4. Have you observed any significant difference in pedestrian behaviors at signalized vs. unsignalized crossing areas? Explain."*

Disabled Pedestrian Hazards

- *"Question 1. What is the most significant safety problem you have observed with handicapped pedestrians as they are approaching or walking away from the bus? How do you handle the situation?*

- *Question 2. Do you have any suggestions on how to solve the problems you have observed with handicapped pedestrians?*

- *Question 3. Do you feel like any of these problems could be solved by different pedestrian crossing designs for handicapped people? If so, explain."*

Closing Suggestions

A closing question was asked to allow the participants to make any type of recommendation and/or suggestion regarding the safety of pedestrians at unsignalized intersection. The closing question asked was "*Question 1. Are there any suggestions or recommendations you would like to make regarding pedestrian safety at unsignalized intersections?"*

Summary of Responses

The following is a summary of the responses to the above questions.

Pedestrian Hazards

- The most significant safety problem identified was pedestrians crossing in front of the transit vehicle.
- Several drivers noted that it was a problem when the pedestrian stands off the curb or so close to the club that the driver has to stop short in order not to hit them with the transit vehicle's fender or mirrors.
- The group felt that education would not help in stopping inappropriate pedestrian behavior.
- All of the drivers agreed that there were too many different types of crosswalk treatment designs. Several suggested using a typical traffic signal configuration (red, yellow, and green) with no flashing as the pedestrian crossing treatment design.
- Most of the participants reported that motorists are confused by the flashing red lights at pedestrian crossings. They think the lights mean caution and do not realize they are supposed to stop. One member felt that some drivers understand the signals, but just aren't obeying.
- One member reported that there were too many crosswalks in general.
- When asked if moving the transit stop location would improve pedestrian safety, most didn't feel it would help. The group did suggest that the transit stops should be located after the intersection, where pedestrians tend to walk behind instead of in front of the transit vehicle.
- All drivers agreed that pedestrians use more caution at signalized crossing areas than nonsignalized crossings.
- The group felt that law enforcement needs to start ticketing pedestrians when they cross against an indicated "DON'T WALK" signal and/or jaywalk.

Disabled Pedestrian Hazards

- All members of the group remarked that there is a problem with individuals in wheelchairs riding in the bike lane and in the street. This makes it hard for transit vehicles that have to make a stop using only the curb lane.
- It was the perception of the group that there were not many problems with handicapped pedestrians and felt they conducted themselves better than the nonhandicapped patrons.

- When asked if they had any problems with the visually impaired, the group reported that they were probably better informed than most passengers.
- There were no suggestions on how to solve any of the problems identified by the group.
- When asked their opinion on the audible crosswalk signals. All agreed that they have helped the hearing impaired.
- When asked if these problems could be solved by different pedestrian crossing designs for handicapped transit patrons, it was suggested that a national standard for pedestrian crossing signals should be developed.
- The group reported that several seniors complain that the crosswalk signals are not long enough for them to make it completely across the street.

When asked “How do you feel about the split midblock pedestrian signal treatment” the responses were as follows:

- One member stated he liked the split midblock pedestrian signal treatment; however, two other members of the group complained that many drivers run that particular light, the drivers stop when it turns red and drive right through the light when it is flashing (it is supposed to be treated as a stop sign).
- One transit driver stated that he felt it was a good crosswalk treatment; it slows the pedestrian down for a moment as they maneuver through the median. They get their bearing in the median and they have a chance to check the traffic on the far side.
- At the Oracle Street location, the crosswalk is in front of where you get off the transit vehicle. Felt it was better when a crosswalk is located upstream of the transit stop so the pedestrian crosses behind the transit vehicle.

Closing Suggestions

In closing, the group members were asked if they had any suggestions or recommendations they would like to make regarding pedestrian safety at unsignalized intersections. The following were their responses:

- All agreed that the crosswalks should always be located upstream of the transit stop.
- All agreed there should not be a transit stop at an intersection with a STOP sign because the transit vehicle will obstruct the view of motorists; vehicles in other lanes do not see the STOP sign and could end up hitting a pedestrian crossing in front of the transit vehicle.
- There should be a national standard for pedestrian crossing treatments.
- Individuals in wheelchairs should be ticketed for riding along the road or bike path.
- Transit stops should be located after an intersection. This eliminates the problem of vehicles turning onto a side street and not realizing the transit vehicle is about to move away from the curb. These turning vehicles can inadvertently cut in front of the transit vehicle.

Key Findings from Bus Driver Focus Group

The following points summarize the main recommendations and suggestions that were gained through the dialog with the transit drivers:

The number one safety concern reported by the transit drivers was pedestrians walking in front of the transit vehicles; however, they did not feel that education will improve this type of behavior. The group suggested having law enforcement officers start ticketing pedestrians to improve these problems.

In regard to the pedestrian and handicap hazards, it was the consensus of the group that there needed to be a uniform type of crosswalk treatment nationally; this would eliminate a lot of confusion on the part of pedestrians in understanding the different types of crosswalk treatments being used.

With regard to handicapped pedestrians, the group felt that in general the handicapped were better informed and used more caution than nonhandicapped pedestrians. However, the transit drivers did agree there was a hazard created by individuals in wheelchairs riding in the street, and some pedestrian crossing signals were not long enough for older and handicapped pedestrians.

The group all felt that crosswalks should be located upstream of the transit stop.

APPENDIX K

ON-STREET PEDESTRIAN SURVEYS

On-street pedestrian surveys were used to obtain the perspectives of pedestrians in regard to their experiences and needs at pedestrian crossing locations. A large sampling of crossing sites was identified from phone interviews and on-site visits. Seven sites with five different treatments were ultimately selected for study. Sites were selected based on pedestrian traffic volumes, pedestrian crossing treatment, and roadway characteristics. The selected sites reflected a wide range of crossing treatments in order to obtain greater perspective of pedestrian experiences.

The five treatments included in the study were two marked crosswalk treatments, an in-roadway warning light treatment, a HAWK treatment, two split midblock signal treatments, and a countdown pedestrian signal treatment at a signalized intersection. Table K-1 lists the selected sites, where they were located, and a summary of key characteristics of each site.

SURVEY DESIGN

The on-street pedestrian survey was divided into three different sections. The first section was to obtain pedestrians' opinions of the crossing treatment. The second section asked general questions for demographic purposes only. The questions used were:

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 sec, <1 min, <2 min, <3 min.
4. Do you think this (name of crosswalk treatment) is safe and effective? Why or why not?
5. Is there anything 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+

TABLE K-1. 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 (TWLTL)	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	1000 ft (305 m)
5	Tucson, AZ	Split Midblock Signal	Six	Raised	3200 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	None and Raised	Not Applicable

The third section consisted of recording several demographic characteristics that were observed only for comparison purposes. These observations included the pedestrian's gender, and ethnicity, observed disabilities, and whether the pedestrian's walking speed was affected. 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 also 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. If willing to participate, the surveyor would read the questions to the participant and record responses. Upon completion of 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. Between 4 and 12 hours were spent at each site. Typically, between 75 and 90 percent of those approached would participate; however, at one location, only about half of those asked agreed to answer the questions. Each site had between 40 and 44 completed surveys for the evaluation.

PEDESTRIAN CROSSING TREATMENT DESCRIPTIONS

Marked Crosswalk Treatment

Two marked crosswalk treatment sites were selected (see Figure K-1). They consisted of high-visibility, ladder-style pavement markings on the roadway to delineate the crossing area. Pedestrian crossing warning signs were present and faced each direction.

Site 1 was a two-way, four-lane roadway with a two-way left-turn lane (TWLTL). The posted speed limit was 35 mph (56 km/h) and the crosswalk was located about 200 ft (61 m) from a signalized intersection (see Figure K-1a). There were transit stops on both sides of the street with benches and bus shelters. Figure K-1b shows the location that a pedestrian would cross to the transit stop if crossing the road at the bus stop. The nearby land use consisted of a grocery store, a strip mall, an elementary school, and a medical building. The population surveyed consisted of transit-dependent individuals, disabled pedestrians, and college students.

(a) Site 1

(b) Site 1

(c) Site 2

(d) Site 2

Figure K-1. Marked Crosswalk Treatments at Sites 1 and 2.

Site 2 was a six-lane roadway with a raised median and left-turn bays in each direction (see Figure K-1c). The posted speed limit was 35 mph (56 km/h) and the marked crossing was about 600 ft (183 m) from a signalized intersection. Transit stops were located on both sides of the major street; however, the transit stop located on the south side was located approximately 150 ft (46 m) from the crossing in front of a strip mall, while the transit stop on the north side was about 400 ft (122 m) from the crosswalk. Site 2 was in a commercial area with nearby residential neighborhoods (see Figure K-1d). The pedestrian population was primarily local residents who were utilizing the transit system.

In-Roadway Warning Lights Treatment

Site 3 had pedestrian-activated in-roadway warning lights, diagonal (zebra) pavement markings, pedestrian crossing warning signs with flashing beacons, and a median refuge island (see Figure K-2). This site was located between a large office complex and a parking garage and was primarily used by employees of the large office complex. The roadway at Site 3 had four lanes with a raised median. The speed limit was 35 mph (56 km/h), and the crosswalk was located midblock.

Figure K-2. In-Roadway Warning Lights Treatment at Site 3.

HAWK Crossing Treatment

The crosswalk treatment referred to as a "HAWK" is a pedestrian crossing signal that is activated by the pedestrian. The signal is dark before activation. After activating the signal light, the progression is: flashing amber ball, solid amber ball, solid red balls, flashing red balls (wig-wag signal heads). The flashing red balls would permit stop-and-go vehicle operations during the flashing "DON'T WALK" interval if no pedestrians were in the crosswalk.

Site 4 was located on a four-lane roadway with a TWLT lane and a bike lane on each side (see Figure K-3). Ladder-style crosswalk markings were present at the crossing. The speed limit was 35 mph (56 km/h) and the pedestrian crossing signal was located at a transit center. As such, the majority of the pedestrian population at this site was transit dependent. With the exception of the transit center and a few small local businesses, the area was predominantly residential.

Figure K-3. HAWK Treatment at Site 4.

Split Midblock Signal Treatment

The split midblock signal treatment uses a traffic signal configuration where a pedestrian uses a pedestrian signal button to activate the signal and cross the first half of the street, then proceeds down a center refuge island approximately 100 ft (31 m) long to push a second pedestrian signal button and activate the second half of the pedestrian traffic signal. This treatment allows the stop time for each direction of traffic to be shorter than if one button activated the entire crossing. If one button activated the entire crossing, then the walk indication would need to be timed to allow the pedestrian to cross both directions of traffic. The split midblock signal permits the walk indication to be times uniquely for each direction.

Site 5 was a six-lane divided roadway with a raised center median (see Figure K-4a). The speed limit was posted at 40 mph (64 km/h) and curbside transit shelters existed on each side of the roadway. The land use consisted of government-supported housing and commercial properties (see Figure K-4b). The apartment building provided housing to many disabled and older transit-dependent pedestrians who were surveyed as part of this study.

(a) Site 5

(b) Site 5

(c) Site 6

(d) Site 6

Figure K-4. Split Midblock Signal Crossing at Sites 5 and 6.

Site 6 was a six-lane divided roadway with three lanes in each direction and a raised median (see Figure K-4c). The posted speed limit was 35 mph (56 km/h). A transit shelter existed on the southbound side, but the northbound transit shelter was temporarily relocated due to nearby roadway construction that was present while the on-street survey was conducted (see Figure K-4d). The pedestrians surveyed consisted largely of medical center employees as well as visitors to the medical center.

Countdown Display with Signal

Site 7 was a signalized intersection with pedestrian crossing signals on each approach that provided a countdown display. The countdown feature started with the beginning of the flashing “DON’T WALK” phase. The site was an intersection of a four-lane roadway with a two-lane roadway. The four-lane roadway was divided by a raised median. The minor two-lane street widened to four lanes at the intersection to accommodate turns. The survey population was a mix of local residents and tourists. Figure K-5a shows one of the crossings. Note the countdown signal shows 4 seconds remaining with the flashing hand (enlargement shown in Figure K-5b). Figure K-5c shows the minor road approach.

(a) (b) (c)

Figure K-5. Countdown Pedestrian Signal.

FINDINGS

Table K-2 summarizes the demographics for the seven sites. The data analysis was categorized based upon the crossing treatment present at the pedestrian interview sites.

Marked Crosswalk

Sites 1 and 2 had treatments that included a marked crosswalk and pedestrian crossing warning signs. The perspective of pedestrians at this type of crossing was that the crossing was unsafe. When asked if they thought the crossing treatment was safe and effective, 85 percent of the Site 2 participants and 66 percent of the Site 1 participants said no. Some of the primary reasons given for not feeling safe were:

- Cars do not stop for pedestrians;
- High traffic volume;
- High-speed traffic; and
- Motorists are not watching for pedestrians.

At Site 1 specifically, it was felt that the location of the crosswalk made it ineffective because it was too far from the bus stop to encourage people to walk to the crossing. This was considered to be especially true since there was no “benefit” to using the crossing without some type of active system to warn drivers to watch for pedestrians.

Pedestrians did feel that this type of crossing treatment was easy for the pedestrian to understand. However, there were comments that the unpredictability of the traffic turning, changing lanes, and/or stopping could make it confusing. When asked if they would add or change the intersection to improve its safety, over 85 percent of the participants at each site indicated that they would. Some of the most common suggestions were:

- Add amber flashing warning lights;
- Install a pedestrian crossing signal; and
- Add advance warning signs.

One simple improvement that was mentioned at both locations was that the faded crosswalks should be repainted to improve their visibility to motorists. At Site 1, additional location-specific suggestions included moving the crossing closer to the transit stop and adding a crossing guard (this was influenced by the close proximity of an elementary school).

Finally, pedestrians were asked if they would walk to a nearby signalized intersection if the current crossing was not available. At Site 1, 49 percent said they would. At Site 2, 65 percent said that they would. The most prevalent reason given by the interviewed pedestrians for walking to the next intersection was that it was safer than trying to cross without a crossing treatment. Of those who said they would not go to the next intersection, the typical reasoning was that it was out of their way and too far to walk. However, one interesting finding was that two of the respondents indicated they would rather cross at an uncontrolled midblock location versus a signalized intersection because of the fewer turning movements made by vehicles.

TABLE K-2. Demographics for Seven Sites.

Demographic	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Number of Completed Surveys	41	40	42	40	40	40	44
Visually Impaired (%)							
Yes	27	0	2	10	85	5	2
No	73	100	98	90	15	95	98
Age Category (%)							
21-40	46	50	50	62	35	58	24
41-55	37	20	40	20	30	20	35
56-64	10	10	10	10	20	12	13
65+	5	20	0	8	15	10	24
Other	2	0	0	0	0	0	4
Gender (%)							
Female	45	45	40	49	38	56	51
Male	55	55	58	51	62	44	44
Not Recorded	0	0	2	2	0	0	5
Ethnicity (%)							
Caucasian	87	53	53	13	60	67	79
Hispanic	13	38	11	83	22	18	14
African American	0	2	23	4	12	0	0
Asian	0	4	9	0	0	11	2
Other	0	4	4	0	4	4	5
Did your trip today start with a bus ride, car, walking or biking? (%)							
Bus	76	33	7	40	78	23	10
Car	7	18	86	20	0	50	45
Walking	17	48	7	38	15	23	45
Bike	0	3	0	3	0	5	0
In a typical week how many times do you cross the street at this location? (frequency)							
Average	6.7	6.5	14.4	8.1	6.9	8.0	17.7
How many streets do you cross in a typical day? (%)							
1 to 5	51	63	86	60	60	63	65
6 to 10	29	20	7	23	15	23	20
11 to 15	12	3	5	10	10	8	5
16 to 20	0	3	0	0	0	3	5
> 20	7	13	2	5	15	3	5
Do you have a current driver's license? (%)							
No	46	43	2	55	67	15	9
Yes	51	57	98	45	33	85	86

In-Roadway Warning Lights

In addition to a marked crosswalk, Site 3 had amber flashing lights on top of the pedestrian crossing warning signs and in the pavement along the crosswalk (see Figure K-2). With the addition of the amber warning lights and in-pavement warning lights, pedestrian perception about safety was somewhat higher than if only a marked crosswalk existed. Nevertheless, the answers are still skewed to the negative side, with over 60 percent of the participants rating the crossing as unsafe. However, even with the inclusion of so many additional features, pedestrians did not typically find the crossing to be confusing or hard to understand.

When asked if the pedestrian thought that the treatment was safe and effective at this location, the reaction was split with 50 percent responding no, 48 percent responding yes, and 2 percent undecided. Of the respondents who were unsatisfied with the in-pavement warning light treatment, the reason given for this response was again typically related to vehicle reactions to the crossing. The pedestrian perception was that the traffic characteristics (speed, volume, and stopping behavior) were unsafe for a pedestrian or that the motorists did not understand that they needed to yield the right of way to pedestrians when the amber lights were flashing. On the positive side, the pedestrians responding yes to this question thought that the lights had helped in stopping traffic and that it was an improvement over the previous crosswalks.

When participants were asked if they would do anything to improve the safety of the crossing, 79 percent responded that they would. Responses to this question brought the following suggestions:

- Pedestrian bridge,
- Red light in place of the amber,
- Greater amount of law enforcement, and
- Moving or adding advance warning signs to a further upstream position.

Most respondents (76 percent) were not willing to walk to the next intersection (550 ft [168 m]) as an alternate means of crossing the roadway.

HAWK

Site 4 had a HAWK pedestrian crossing treatment. With this type of a crossing treatment, the survey responses from the pedestrians again moved toward a more positive perception of safety as the crossing treatment control increased. At this location, 75 percent of the participants indicated that they felt safe at this crossing. Ninety-eight percent responded that the signal was not hard to understand. Although the general perception of this crossing was that the pedestrians liked the signals because they stopped the traffic, there was still the complaint that the unpredictability of the traffic was a concern (i.e., whether motorists would stop for the signal).

When asked if there was anything that could improve the safety at this crossing location, 50 percent of the people responded yes. The pedestrians felt that the following could improve this crossing’s safety:

- A pedestrian bridge,
- Longer crossing time (i.e., walk indication), and
- Law enforcement for speeding and compliance with signal.

Lastly, the pedestrians were asked if they would walk to the next signalized intersection if this crossing was not available. Seventy-five percent said that they would not go to the next intersection (about 1000 ft [305 m] away) because it was too far out of the way for them to walk. The 25 percent who indicated they would go to the next intersection said they would do so because it is safer and the traffic volume is too high to cross without a signal.

Split Midblock Signal

The traffic control provided at the Split Midblock Signal included a traffic signal along with a pedestrian median refuge island. In this situation, the reactions of the pedestrians at Site 6 were overwhelmingly positive, with 78 percent of the pedestrians responding that the crossing is very safe. Site 5 responses were more diverse, with an even spread of responses from very safe to unsafe. The researchers feel that the difference of perceptions between these two locations could be largely influenced by the type of pedestrian traffic in the area (see Table K-2 for demographics). The feeling of safety is much lower for Site 5, which had an older population and more disabled pedestrians. Although Site 6 is located at the hospital, the pedestrians who were crossing the street were primarily hospital staff and visitors. The older and/or disabled people at this site are typically being dropped off prior to parking due to the long walk required between the parking lot and the hospital entrance.

When the pedestrians were asked if they thought this type of crossing treatment was safe and effective, 78 percent at Site 6 and 68 percent at Site 5 responded yes. The comments made by these responders were primarily that they liked having the signal to stop the traffic. Of the respondents who said no, comments were made that not all of the cars stop for the signals. At Site 6, a significant number of both the positive and negative respondents (23 percent) commented that they did not like the median treatment because it took them out of their way to reach the second crossing signal and therefore made the crossing inefficient for pedestrians.

Most pedestrians did not feel that the Split Midblock Signal treatment was hard to understand. Only 15 percent at Site 5 and 20 percent at Site 6 felt that it was confusing. Comments made indicated that the median was confusing to some users and that motorists didn't understand how to act at this crossing treatment.

When asked if they would change anything to improve the safety of this crossing location, over 40 percent of the respondents at each location indicated they would. Due to the diverse feelings of the participants, the ideas for improvement varied greatly between the two crossings. At Site 5, the main concerns were increasing the available walk time, improving the audible signals, and increasing law enforcement for speeding. These responses were influenced by the disabled and older population of the area. At Site 6, the primary concerns were that there was not a direct path between the crossing and the hospital and that the median should allow pedestrians to go straight across without the jog in the path which takes them off of their desired route.

At Site 5, it was not appropriate to ask pedestrians about going to the next signalized intersection to cross due to the distance to the next intersection from the current crossing (over 3200 ft [975 m]). When this question was asked at Site 6, 75 percent indicated that they would not walk to the next signal in order to cross the street (about 950 ft [290 m]). Again, it was stated by the pedestrians that the crossings were too far out of their way, making it inefficient for them in getting to their destination. Of the people who indicated they would go to the next intersection, common reasons provided included safety concerns and a desire to cross at a controlled location.

Countdown Indication at a Signalized Intersection

The final treatment studied was a signalized intersection with a pedestrian countdown indication. The participants in the survey included a mix of both local residents who cross at this location frequently and first-time visitors.

The pedestrians were again asked to rate their feeling of safety as they crossed this intersection. The split of responses was very even from very safe to unsafe. The reasons given for feeling unsafe were primarily related to the traffic that was either turning or did not stop. However, when asked if this was a safe and effective crossing treatment, 68 percent responded yes. These pedestrians felt that the signal made it easy to cross and that the countdown lets you know when the signal was going to change. Of those who did not feel safe at the crossing, common perceptions were that:

- The WALK time was not long enough,
- There needed to be more law enforcement, and
- Turning vehicles made it unsafe to cross.

At this location, it was observed by the researchers that the left-turning traffic frequently interfered with the pedestrian WALK phase and that the right-turning traffic frequently stopped within the crosswalk.

Of the pedestrians interviewed, 30 percent felt the crossing was hard to understand. Most commented that the turning traffic made them unsure of when to cross and they did not understand what the countdown numbers meant. The pedestrians were asked if they would add or change anything to improve the safety at this intersection. Fifty-two percent responded that they would. Of these people, the following items are what they would like to see at the crossing:

- No vehicle turns allowed during the pedestrian crossing time,
- Adjust the amount of time allotted for walking,
- Increased police enforcement,
- Audible signals, and
- Better pavement markings for visibility.

Comparison of Selected Findings

Distance to Nearest Signal

As part of the on-street pedestrian surveys, 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 that was located at either 550, 950, or 1000 ft (168, 290, or 305 m). For the site with a signalized intersection about 200 ft (61 m) from the crossing, about half of those interviewed would walk to that crossing. The remaining site where this question was appropriate did not follow similar findings (i.e., half or less being willing to walk 200 ft (61 m) or more to a controlled crossing). A much higher percentage indicated that they would be willing to walk to another crossing. Over 65 percent of the respondents at Site 2 indicated that they would walk 600 ft (183 m) to cross at a signalized crossing. The greater 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 upon the "weather" or other factors.

Pedestrian Delay Thresholds

The participants were asked, "What is the maximum amount of time a person should have to wait to cross this street?" Their responses are summarized in Table K-3. When asked, about 75 percent of pedestrians feel that they should have to wait 1 minute or less before being able to safely cross a street (the remaining 25 percent report that they are willing to wait longer than 1 minute). Of course, there may be a significant difference between pedestrians' perceived tolerable delay and their actions.

TABLE K-3. Results of Perceived Pedestrian Delay Thresholds (%).

Delay Threshold	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
<30 sec	20	28	**43**	**40**	25	23
<1 min	**29**	**60**	38	35	**48**	**50**
<2 min	24	5	14	13	18	23
<3 min	24	3	5	5	8	5
Other	2	5	0	5	3	0
Sample Size	41	40	42	40	40	40

Pedestrian Safety Ratings

It was found through this study 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 K-6, where the average pedestrian safety ratings for each site were plotted. The ratings were based on a scale where 1 indicates very safe and 5 indicates unsafe. Figure K-6 also shows the sites as the pedestrian crossings treatments progress from least amount of control at the left to most 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 (Site 5 and 6). It is believed by the researchers that this variance is due to the fact that a pedestrian crossing at a major signalized intersection has a larger number of turning vehicles in conflict with the pedestrians which negatively impacts their feelings of safety.

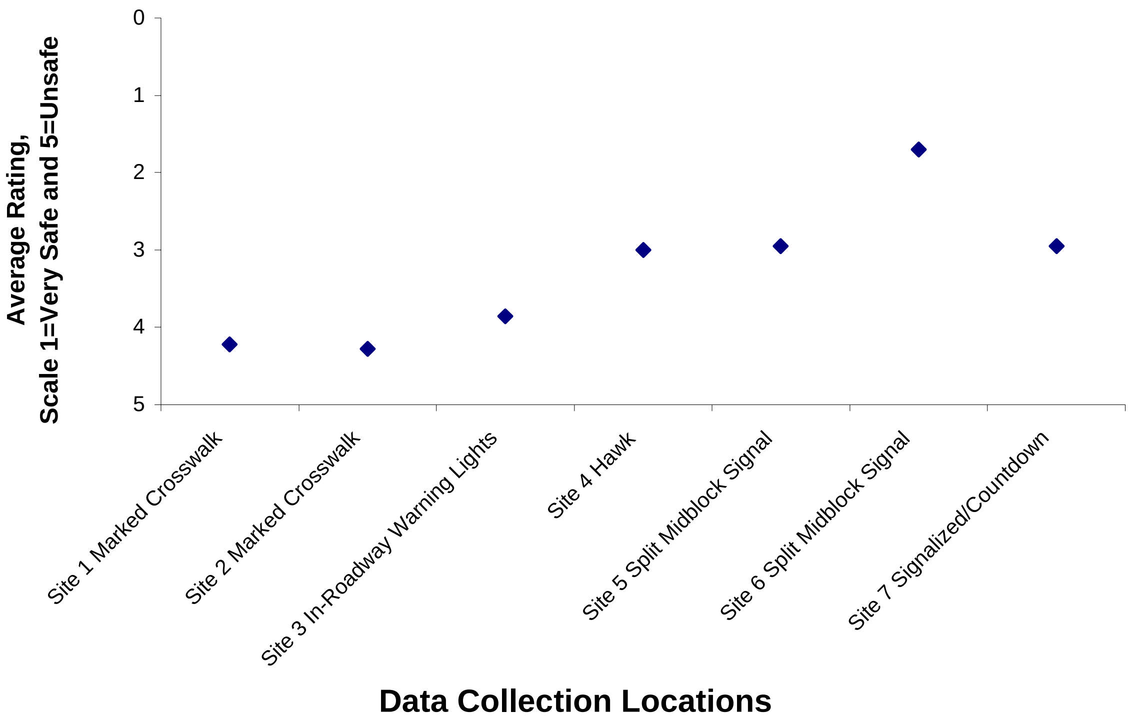


Figure K-6. Average Pedestrian Safety Ratings.

CONCLUSIONS

When determining the amount of traffic control to be used at a pedestrian crossing location, there are many factors that should be considered. Based on the responses of the survey participants, the factors that have the greatest influence on the pedestrians' responses are:

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

Other findings from the survey included:

- At distances of 550 to 1000 ft (168 to 305 m), only about 25 percent of the respondents would walk to a signalized intersection.
- About 75 percent of the pedestrians felt they should have to wait 1 minute or less before crossing the street.
- 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.

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

Finally, the perception of pedestrians can be greatly influenced based on their own abilities. In the case of the two sites with the Split Midblock Signal treatment (Sites 5 and 6), perceptions were greatly altered depending on the pedestrian population. At the location with a greater number of disabled or older people crossing, the extended median was viewed favorably. However, at the location without this type of pedestrian traffic, the jog in the pedestrian path was considered to be a delay and therefore not an effective crossing design.

APPENDIX L

MOTORIST COMPLIANCE TO ENGINEERING TREATMENTS AT MARKED CROSSWALKS

APPENDIX SUMMARY

This Appendix describes the evaluation of engineering treatments that can improve the safety of pedestrians crossing in marked crosswalks on high-volume, high-speed roads. The research team collected extensive data at 42 study sites in different regions of the country to gauge the effectiveness (as measured by motorist yielding/stopping) of various engineering treatments. Motorist yielding data were collected for crossing pedestrians from the general population as well as staged crossings by the research team. In preliminary analyses, the treatments were grouped into three categories based upon function and design: (a) red signal or beacon devices, (b) "active when present" devices, and (c) enhanced and/or high-visibility treatments. The authors found the red signal or beacon devices to be the most effective, with yielding rates above 94 percent for all study sites. Other treatments had varying rates of motorist yielding, and it was shown that several variables (e.g., number of lanes and speed limit, in particular) were statistically significant in predicting motorist yielding. Most of the treatments in the other two categories had statistically similar motorist yielding levels. An implementation matrix (currently being finalized by the research team) is recommended to assist in selecting appropriate crossing treatments for streets with known road widths, traffic volumes, and pedestrian volumes. The authors also recommend the adoption of red signal or beacon devices (e.g., midblock signals, half-signals, HAWK) into the engineer's toolbox to improve pedestrian crossing safety along high-volume, high-speed roads.

INTRODUCTION

This Appendix summarizes the research conducted to evaluate selected engineering treatments at pedestrian crossings. To determine which engineering treatments were effective under certain street and traffic conditions, a research team from the Texas Transportation Institute (TTI) collected extensive site and observational data at 42 pedestrian crossings in several regions of the country. These 42 pedestrian crossings were all marked crosswalks with a supplemental traffic control device (e.g., high-visibility signs, flashing beacons, crossing flags, etc.). Ideally, the effectiveness of these treatments would have been determined by a before-and-after analysis of pedestrian-vehicle crashes. Because of the timing and duration of the study, as well as several other limiting factors, the research team selected several surrogate measures of effectiveness (MOEs), chief among these being motorist compliance (yielding or stopping) at marked crosswalks.

This Appendix reports on the effectiveness of these pedestrian crossing treatments at unsignalized intersections as measured by motorist yielding. The Appendix also describes an analysis of street and traffic characteristics (e.g., speed limit, number of lanes, traffic volumes, etc.) that could influence motorist yielding at unsignalized intersections. The Appendix concludes with recommendations for improving pedestrian safety at unsignalized intersections.

BACKGROUND

Many pedestrians find it difficult and unsafe to cross high-volume, high-speed streets, particularly in the absence of a traffic signal. This difficulty is despite the fact that most (if not all) state vehicle codes in the United States dictate that motorists are to yield or stop for pedestrians in marked crosswalks at intersections without traffic signal control. In a 2002 report, Zegeer et al. (*113*) provided recommendations on the use of marked crosswalks for varying street widths and traffic levels. The study by Zegeer et al. (*31*) supporting these recommendations indicated that above certain roadway widths and traffic levels, unmarked crosswalks had lower crash rates than marked crosswalks. Some traffic engineers and practitioners interpreted this to mean that marked crosswalks should not be provided on wide, high-speed streets. However, the 2002 marked crosswalk guidelines clearly indicate the road width and traffic speed at which engineers should consider additional traffic control devices above and beyond a marked crosswalk (for more elaboration, see http://www.walkinginfo.org/pedsafe/moreinfo_crosswalk.cfm).

If marked crosswalks alone are insufficient on wide high-speed streets, then the question becomes "What additional traffic control devices can be provided in addition to marked crosswalks?" Zegeer's 2002 guidelines recommended the following types of devices: traffic calming (road narrowing and curb extensions), traffic signals with pedestrian signals, raised medians, and enhanced overhead lighting. In a 2001 report (*44*), Lalani compiled an international inventory of *Alternative Treatments for At-Grade Pedestrian Crossings* that are intended to improve the safety of a marked crosswalk. The treatments in Lalani's 2001 report included:

- Supplemental high-visibility signs and markings;
- Advance placement of STOP or YIELD limit lines;
- Pavement legends for pedestrians;
- Overhead and side-mounted flashing beacons, lights, and signs;
- In-roadway warning lights;
- Pedestrian crossing flags;
- Innovative traffic signal control strategies;
- Median refuge islands;
- Traffic calming measures;
- Street lighting;
- Turn restrictions; and
- Miscellaneous other treatments such as curb ramps, tactile surfaces, pedestrian railings, etc.

The inventory of alternative treatments in this 2001 report was comprehensive and provided references to reports about effectiveness. However, as an *Informational Report*, it made no recommendations about where each treatment is most effective or the street environment in which it could be used.

A literature review by the research team found numerous reports and articles evaluating the effectiveness of various pedestrian crossing treatments. Most of the available literature reported effectiveness in terms other than actual crash rate reductions. In many cases, surrogate MOEs for pedestrian safety were used, such as motorist yielding, vehicle-pedestrian conflicts, vehicle braking distance, vehicle speeds, and pedestrian behavior. The most common MOE reported in the literature was motorist yielding (or stopping where required) for pedestrians in crosswalks. Table L-1 provides a summary of the literature in regard to motorist yielding at various pedestrian crossing treatments. Motorist yielding is expressed as the percentage of motorists that yielded when one or more pedestrians were present.

TABLE L-1. Summary of Motorist Yielding at Innovative Pedestrian Crossing Treatments.

Crossing treatment	Evaluation studies	Number of sites	Range in yielding (%)	Average yielding (%)
Half-signal	(*14*)	1	99	99
HAWK signal beacon	(*3*)	1	93	93
In-roadway warning lights	(*18, 86, 57, 114, 24*)	11	8 to 100	66
Overhead flashing beacon (pushbutton activation)	(*2, 80, 26, 16, 17*)	10	13 to 91	52
Overhead flashing beacon (passive activation)	(*15*)	not available	not available	74
In-street crossing signs	(*26*)	7	44 to 97	77
High-visibility signs and markings	(*26*)	1	52	52

Note: Additional detail for each evaluation study (as well as related literature on pedestrian crossing treatments) can be found in Appendices C and D of this final project report.

STUDY METHODOLOGY

The data collection phase of the TCRP/NCHRP study had several objectives, as the TTI research team was tasked with recommending effective pedestrian crossing treatments as well as a revised *MUTCD* pedestrian traffic signal warrant. The evaluation of crossing treatment effectiveness focused on motorist compliance (i.e., yielding or stopping as required) at marked crosswalks. However, data for several other MOEs were also gathered, including vehicle-pedestrian conflicts, pedestrian looking and crossing behavior, and motorist stopping behavior. This section focuses on data collection for motorist compliance, as the study conclusions are based solely on this MOE. A more detailed description of all data collection procedures can be found elsewhere in this final project report.

Experimental Design

To collect motorist compliance at marked crosswalks with various engineering treatments, the research team observed pedestrians attempting to cross at designated treatment study sites. In addition to observing pedestrians from the general population, members of the research team also staged street crossings in a consistent manner at each of the study sites. These "staged" crossings controlled the variability between pedestrians that may be present in different regions of the county (e.g., pedestrians in one region may be more assertive than pedestrians in other regions). The staged crossings also ensured that the research team had a sufficient sample size at study sites with moderate to low pedestrian volumes.

The research team did not gather crash data to measure crossing treatment effectiveness for several reasons. The timing and duration of the study were contributing factors, as was the timing of the installation of promising treatments. The research team also wanted to collect data that were consistent with the published literature on crossing treatment effectiveness; thus, a cross-sectional study of motorist compliance was chosen. A classic before-and-after study with control locations would have been desirable, but ultimately the research team had to balance the study duration, number of study sites, different crossing treatments in different regions, and travel costs into the experimental design selection.

Study Sites

In total, 42 study sites were selected in seven different states (Table L-2). 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 were not collected from a single city. This could not be avoided for two treatments (i.e., HAWK and in-street crossing sign) that were each only installed in a single city. The sites were chosen to focus on arterial streets, with a range of operational and design characteristics (e.g., number of lanes, presence of median refuge island, speed limit, etc.). 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 vs. less-than-friendly street design, aggressive drivers, etc.).

Descriptions of Crossing Treatments

The research team categorized the crossing treatments into three basic types according to function and design, as listed in Table L-2.

TABLE L-2. 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), pedestrian flags	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

1. **Red signal or beacon –** devices that display a circular red indication to motorists at the pedestrian crossing location. Examples include a midblock traffic signal, half-signal, or HAWK signal beacon.

2. **Active when present –** devices that are designed to display a warning only when pedestrians are present or crossing the street. Examples include in-roadway warning lights, flashing amber beacons, and pedestrian crossing flags.

3. **Enhanced and/or high-visibility –** devices and design treatments that enhance: (a) the ability of pedestrians to cross the street and (b) 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 include in-street pedestrian crossing signs, high-visibility signs and markings, and median refuge islands.

Data Collection Protocol

The research team used video cameras as well as palmtop computers to collect data at each study site. The video cameras captured video for later review and analysis, and these video recordings were the ultimate source of data for motorist compliance. The video cameras were inconspicuously mounted so as to avoid altering pedestrian or motorist behavior. The palmtop computers were used by the research team to collect additional data about pedestrian characteristics and behavior.

The research team recorded both general population pedestrian crossings, as well as staged pedestrian crossings by data collection personnel. The staged pedestrian crossings were conducted because the research team felt that consistent presentation of a pedestrian intent to cross is critical for comparing motorist yielding results from different areas of the country. The research team hypothesized that pedestrian positioning, stance, and assertiveness could affect a motorist's decision to stop or yield at a pedestrian crossing. Detailed data collection protocol for the general population and staged pedestrian crossings is documented elsewhere in this final project report.

Data Reduction and Analysis

The staged pedestrian crossings were conducted on weekdays in October and November 2003. The video recordings were reviewed by trained technicians later in 2004. In the case of questionable pedestrian crossings that could be interpreted several different ways, the video was reviewed by one of the study's engineers for a final determination.

For this study, motorist yielding was calculated as the number of motorists that did yield or stop for a pedestrian divided by the total number of motorists that should have yielded or stopped for a pedestrian (Equation 1). A value of 25 percent compliance means that only one of four motorists that should have yielded did actually yield to a pedestrian.

Equation 1
$$\text{Motorist yielding compliance (\%)} = \frac{\text{number of motorists yielding to pedestrians}}{\text{total number of motorists that should have yielded}}$$

Motorist yielding was calculated for each individual pedestrian attempting to cross the street. If no vehicles were at the study site when a general population pedestrian crossed, that crossing was not included in the calculations (i.e., there were no motorists that should have yielded). Average compliance rates were then calculated by vehicle approach and the entire crossing. After ensuring that no significant differences existed between the two different vehicle approaches, the motorist yielding percentages for the entire crossing (study site) were used in further analyses.

In addition to calculating the motorist yielding from the staged pedestrian crossings, the research team also reduced data corresponding to the general population pedestrian crossings. Motorist yielding values from both types of pedestrian crossings were included in initial analyses. With a few exceptions that will be discussed in the next section, motorist yielding values were similar and the research team utilized the staged crossing compliance values because of larger samples sizes and higher personal confidence.

FINDINGS AND DISCUSSION

Summary of Motorist Yielding Rates

Tables L-3 and L-4 summarize the measured motorist yielding data from both types of pedestrian crossings (general population as well as staged), and also includes 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 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 developed the following conclusions from Tables L-3 and L-4:

- **The motorist yielding 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 greater than 10 percent difference between general population and staged pedestrians. At three Los Angeles sites, we 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: (a) motorists were more likely to yield to larger groups of pedestrians than the single staged pedestrian, and (b) 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 of 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 (56 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).

- **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” have a wide range of compliance rates as shown in Tables L-3 and L-4. The research team concluded that there were other factors (such as traffic volume, roadway width, street environment, etc.) affecting compliance rates. These factors are discussed in more detail later in this Appendix.

TABLE L-3. Summary of Motorist Yielding Compliance from Three Sources for Red Signal or Beacon and Active When Present.

	TCRP D-08/NCHRP 3-71 Study						Other Studies		
	Compliance - Staged pedestrian crossing			Compliance – General population pedestrian crossing			Compliance – Literature review (from Table L-1)		
Crossing Treatment	# of sites	Range (%)	Average (%)	# of sites	Range (%)	Average (%)	# 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 L-4. Summary of Motorist Yielding Compliance from Three Sources for Enhanced and/or High Visibility Treatments.

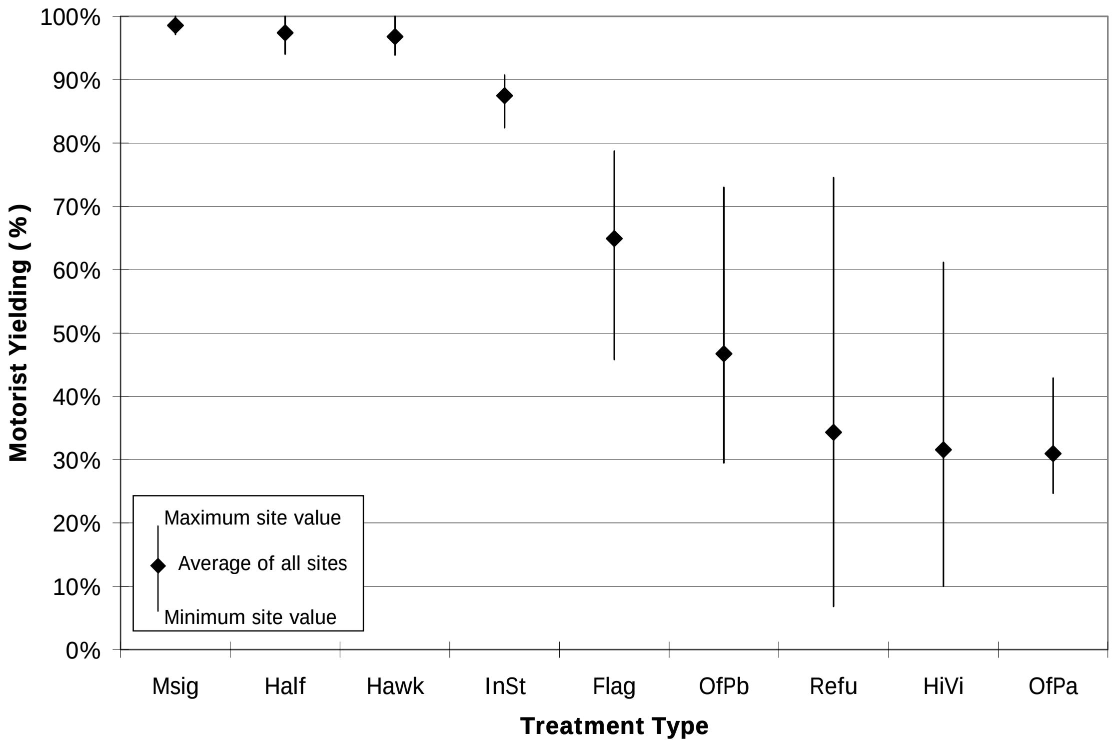
	TCRP D-08/NCHRP 3-71 Study						**Other Studies**		
	Compliance - Staged pedestrian crossing			**Compliance – General population pedestrian crossing**			**Compliance – Literature review (from Table L-1)**		
Crossing Treatment	# of sites	Range (%)	Average (%)	# of sites	Range (%)	Average (%)	# of sites	Range (%)	Average (%)
Enhanced and/or High-visibility									
In-street crossing signs (25 to 30 mph [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 [56 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.

Significant Differences in Treatment Effectiveness

As indicated in the previous section, many crossing treatments had wide ranges in the measured compliance rate (see Figure L-1). Thus, even though the average compliance may be greater for some treatments, the wide range in compliance may not permit one to draw the conclusion 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:

- One-way 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 determine which crossing treatments have statistically similar 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 L-1. Site Average and Range for Motorist Yielding by Crossing Treatment.

The results of the statistical analyses are summarized in the following paragraphs:

- **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.** There were only three treatments that 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.

Street Characteristics that Influence Treatment Effectiveness

Because of the wide range in measured compliance rates between sites, the research team hypothesized that there were other variables that 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 determine those factors that most affected the range in compliance rates.

Effect of Number of Lanes

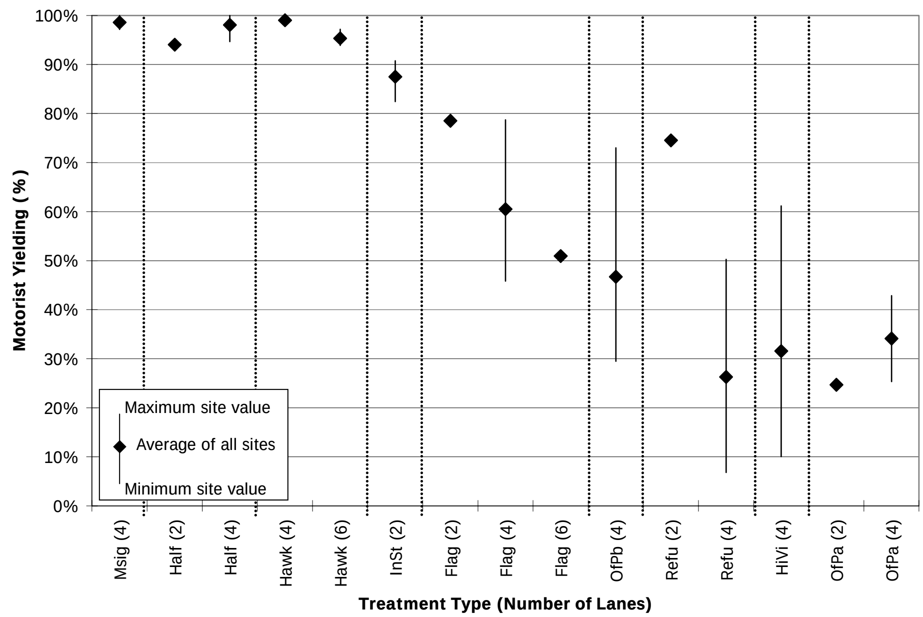
The top chart in Figure L-2 shows the motorist yielding by treatment type (major grouping) and number of lanes. For the “red signal or beacon” devices, the number of lanes did not have an effect on performance. Within the study set, red devices were on two-, four-, and six-lane roadways. A compliance 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 upon the number of lanes.

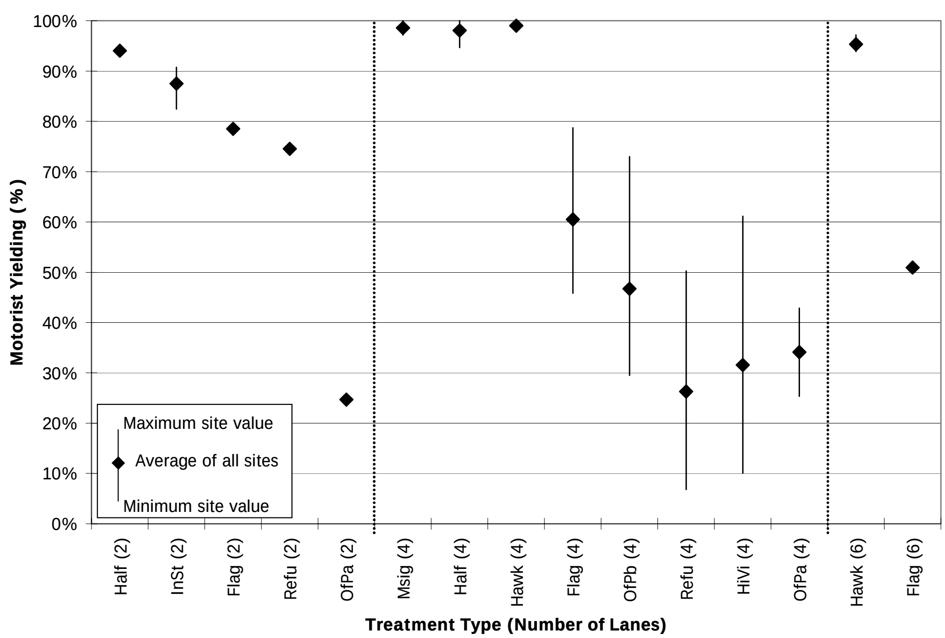
The bottom chart in Figure L-2 regroups the data in the top chart of Figure L-2 by number of lanes. As seen in the bottom chart of Figure L-2 for four-lane highways, the red devices have a much higher compliance rate than the other non-red devices. All but one of the devices on a two-lane roadway performed 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 $\alpha = 0.05$ level) in predicting motorist yielding at treatments.

Grouped by Treatment Type



Grouped by Number of Lanes



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 L-2. Motorist Yielding by Crossing Treatment and Number of Lanes.

Effect of Speed Limit

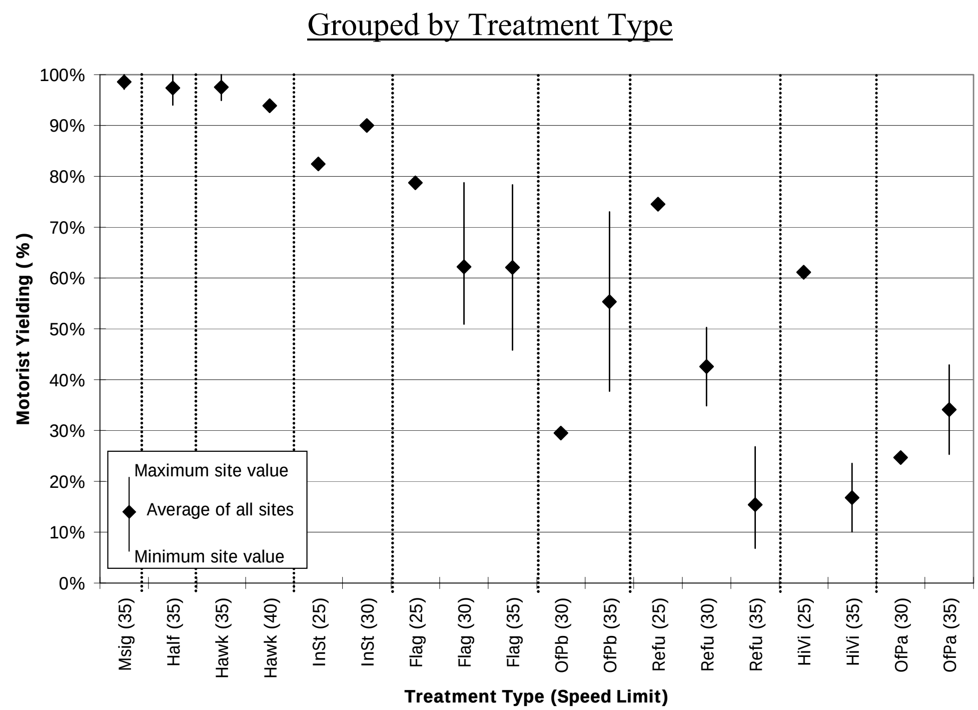
Figure L-3 shows motorist yielding by treatment type and speed limit. The bottom chart in Figure L-3 regroups the data and shows the compliance by speed limit and then treatment type.

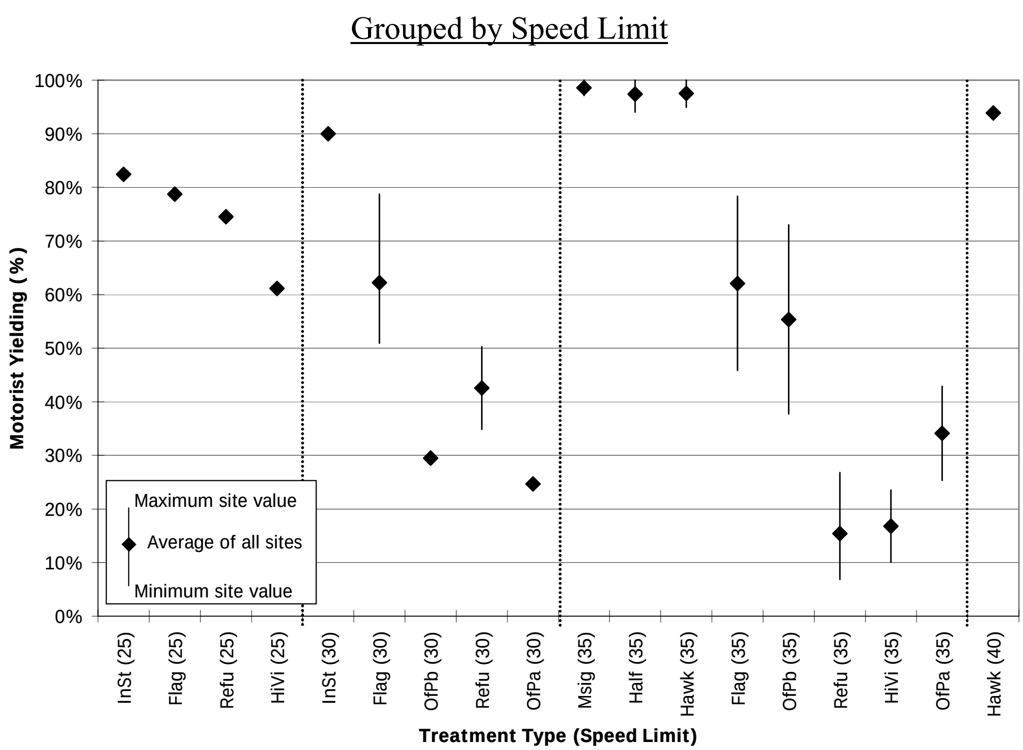
As seen in the top chart of Figure L-3, in-street pedestrian crossing signs and overhead flashing beacons (pushbutton activation) appear to have an increase in compliance with an increase in speed; however, the average compliance rates are not statistically different. Stated in another manner, the performance at these two devices are independent of the posted speed limit. The performance of the overhead flashing beacons (passive activation) does show a statistically different compliance rate between the device on the 30 mph (48 km/h) roadway and the device on the 35 mph (56 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 (56 km/h) site was in a residential area. Since other devices show a decrease in compliance with an increase in speed limit, this finding 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 does have an effect on the performance of the device. Flags, refuge islands, and high-visibility markings all perform better on the lower speed roadways.

Figure L-3 shows a clear break between two groups of treatments at the 35 mph (56 km/h) speed limit. The most effective treatments are all red signal or beacon devices. On a 35 mph (56 km/h) roadway, the best compliance rate observed for a treatment that is not showing a red indication to the motorist is approximately 63 percent. Compliance rates go as low as 8 percent for the 35 mph (56 km/h) speed limit group. For the 25 mph (40 km/h) speed limit roadways, all five 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 $\alpha = 0.10$ level) in predicting treatment compliance when accounting for interaction between other model variables.





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 L-3. Motorist Yielding by Crossing Treatment and Posted Speed Limit.

CONCLUSIONS

The research team concluded the following after a thorough analysis of motorist yielding:

- **The crossing treatment does have an impact on the motorist yielding.** Those devices 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 include midblock signals, half-signals, and HAWK signal beacons. Nearly all of 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 yielding for many crossing treatments varied considerably among sites.** For example, treatments in the "active when present" and "enhanced and/or high-visibility" have a wide range of compliance rates as shown in Table L-1. 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 there were other factors (such as traffic volume, roadway width, street environment, etc.) affecting compliance rates.

- **The number of lanes being crossed can affect the performance of treatments.** All but one of the treatments on the two-lane roadways performed at better than a 75 percent compliance rate. On four-lane roadways, compliance ranged from below 30 percent to 100 percent.

- **The posted speed limit can affect the performance of treatments.** Flags, refuge islands, and high-visibility markings all have better compliance rates on the lower speed roadways. On a 35 mph (56 km/h) roadway, the best compliance rate observed for a treatment that is not showing a red indication to the motorist is approximately 58 percent. Compliance rates for the devices on 25 mph (40 km/h) streets all were above 60 percent. Compliance rates go as low as 15 percent for streets with a 35 mph (56 km/h) speed limit.

RECOMMENDATIONS

The authors provide the following recommendations:

- Red signal or beacon devices need to be added to the engineer's toolbox for pedestrian crossings. The study results indicated that all red signal or beacon devices were effective at prompting high levels of motorist yielding on high-volume, high-speed streets. However, only a midblock 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 are unable to employ those traffic control devices that are most effective for pedestrians on wide, high-speed streets. The authors have presented information to the National Committee on Uniform Traffic Control Devices (NCUTCD) in an attempt to revise the pedestrian traffic signal warrant as well as recognize a new class of traffic control signals for pedestrians (to include the red signals and beacons evaluated in this study).

- There is a need to better inform motorists and enforce the right-of-way laws at marked crosswalks. In most (if not all) states, motorists are required by law to yield or stop for pedestrians in a marked crosswalk. The details within each state's laws may differ, but these crosswalk laws are seldom enforced. Police in one of the study cities had recently performed crosswalk enforcement, and informal conversations with pedestrians at several study sites in this city revealed that this enforcement had been effective in terms of increasing motorist awareness. Our experience with motorist yielding at these same study sites seemed to confirm this anecdotal information.

APPENDIX M

WALKING SPEED

INTRODUCTION

Pedestrians have a wide range of needs and abilities. The *Manual on Uniform Traffic Control Devices for Streets and Highways* (*MUTCD*) (*1*) 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 who walk slower than normal, or pedestrians who use 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 (0.7 to 1.3 m/s) as discussed in the following sections. In 2002, the Public Rights-of-Way Access Advisory Committee released their draft guidelines for public comment (*115*). With respect to pedestrian walking speeds used for determining minimum pedestrian clearance times at signalized intersections, a universal maximum pedestrian walking speed of 3.0 ft/s (0.9 m/s) was recommended. This TCRP/NCHRP project collected walking speed data as part of the study. This Appendix summarizes the field data findings and compares those findings to other research.

PREVIOUS WORK

Source of *MUTCD* Walking Speed

A specific walking speed was introduced in the 1961 *MUTCD* with the sentence, “Normal walking speed is assumed to be 4 ft/s (1.2 m/s).” J.N. LaPlante and T.P. Kaeser, in material prepared for use by the NCUTCD, reported on discussions with long-term members of the Committee (*116*). They stated that the 4 ft/s (1.2 m/s) speed was introduced following research done in the early 1950s that indicated that 4 ft/s (1.2 m/s) is the average walking speed of *all* crossing pedestrians. LaPlante and Kaeser note that the 1961 *MUTCD* states that the 4 ft/s (1.2 m/s) is a “normal” speed, and not necessarily a design or critical speed. The Millennium edition of the *MUTCD* explicitly notes the need to consider pedestrians who may move at a speed slower than the “normal” 4 ft/s (1.2 m/s).

Pedestrian Walking Speed

In LaPlante and Kaeser’s review of the unpublished research from the 1950s, they noted that the research showed that a walking speed of 4 ft/s (1.2 m/s) was considered an average speed for all crossing pedestrians, including men and woman and all age groups (*116*). However, the research did note that the speed frequency distribution curves indicated a break point in the curves that generally corresponded to a 15th percentile walking speed. For all pedestrians, this value was 3.5 ft/s (1.07 m/s), which was considered a critical slow walking speed of particular interest to traffic engineers. The research also noted variations in speeds for other classes of pedestrians, such as elderly pedestrians, with a 50th percentile speed of about 3.5 ft/s (1.07 m/s) and a 15th percentile speed of about 3.0 ft/s (0.9 m/s).

The 1982 *Transportation and Traffic Engineering Handbook* (*117*) cites research by Robert Sleight that indicates 50th percentile walking speeds of about 4.5 ft/s (1.4 m/s), and 15th percentile speed of about 3.3 ft/s (1.0 m/s) for elderly pedestrians and about 3.7 ft/s (1.13 m/s) for other adults. The Handbook suggests that "for the relatively slow walkers, speeds of 3.0 to 3.25 ft/s (0.9 to 1.0 m/s) would be more appropriate" than 4.0 ft/s (1.2 m/s).

In 1996, Knoblauch et al. (*118*) reported on walking speeds of younger (ages 13 to 64) and older pedestrians (65 and over). Table M-1 summarizes findings by age from the study. Also shown are some of the differences Knoblauch et al. found between age and roadway characteristics that are also being considered as part of this TCRP/NCHRP study. Knoblauch et al.'s statistical tests indicated that walking speeds are influenced by a variety of factors. They note that while the following were statistically significant, the differences were not meaningful for design:

- Functional classification,
- Vehicle volumes on street being crossed,
- Street width,
- Weather conditions,
- Number of pedestrians crossing in a group,
- Signal cycle length,
- Timing of the various pedestrian-signal phases,
- Whether right turn on red is allowed,
- Pedestrian signals,
- Medians,
- Curb cuts,
- Crosswalk markings,
- Stop lines, and
- On-street parking.

Knoblauch et al. suggest a value of 4 ft/s (1.2 m/s) for younger pedestrians and 3 ft/s (0.9 m/s) for older pedestrians for traffic signal design.

In 1998, Guerrier and Jolibois (*119*) published a study of pedestrian crossing speeds in Miami, Florida, and found an average crossing speed of 4.42 ft/s (1.35 m/s) for younger and 3.19 ft/s (0.97 m/s) for older pedestrians and 15th percentile speeds of 3.09 ft/s (0.94 m/s) overall, 3.31 ft/s (1.0 m/s) for younger, and 2.20 ft/s (0.7 m/s) for older pedestrians.

In 1999, Milazzo et al. (*120*) reviewed past research and guidelines for pedestrian crossing speeds. They noted that the 1994 *Highway Capacity Manual* uses a value of 4.5 ft/s (1.4 m/s) as a typical walking speed, but 4.0 ft/s (1.2 m/s) as the "assumed 15th-percentile crosswalk walking speed when pedestrian timing requirements are computed." Their paper is in turn cited in the 2000 *Highway Capacity Manual* (*109*) references for the following: average walking speed of 4.0 ft/s (1.2 m) where there are 0 to 20 percent elderly pedestrians and 3.3 ft/s (1.0 m/s) where there are greater than 20 percent elderly.

TABLE M-1. Knoblauch et al. (*118*) Findings on Walking Speeds at Signalized Intersections for Pedestrians Who Complied with the Pedestrian Signal Indication.

		Number		Mean (ft/s) [m/s]		15th Percentile (ft/s) [m/s]	
		Young	Old*	Young	Old	Young	Old
All Ped		2081	2379	4.79 (1.46)	3.94 (1.20)	3.97 (1.21)	3.08 (094)
Gender	Male	984	1180	4.96 (1.51)	4.14 (1.26)	4.17 (1.27)	3.24 (0.99)
	Female	1097	1198	4.64 (1.41)	3.74 (1.14)	3.88 (1.18)	2.97 (0.91)
Street Design	Major Arterial	1382	1520	4.83 (1.47)	4.01 (1.22)	4.02 (1.23)	3.15 (0.92)
	Collector	163	256	4.54 (1.38)	3.87 (1.18)	3.86 (1.18)	3.07 (0.94)
	Local	536	603	4.76 (1.45)	3.77 (1.15)	3.93 (1.20)	2.89 (0.88)
Crosswalk Marking	Standard	1323	1546	4.81 (1.47)	3.98 (1.21)	3.97 (1.21)	3.10 (0.94)
	High Visibility	758	833	4.75 (1.45)	3.86 (1.18)	3.99 (1.22)	3.06 (0.93)
Roadway Width	Narrow (8.5 – 13 m)	893	1017	4.73 (1.44)	3.73 (1.14)	3.90 (1.19)	2.97 (0.91)
	Moderate (13.1 – 15.6 m)	514	670	4.77 (1.45)	4.01 (1.22)	4.01 (1.22)	3.16 (0.96)
	Wide (15.7 – 31.7 m)	674	692	4.88 (1.49)	4.18 (1.27)	4.06 (1.24)	3.31 (1.01)
Number of Lanes	2	1009	1187	4.75 (1.45)	3.81 (1.16)	3.93 (1.20)	3.02 (0.92)
	3-7	1072	1212	4.82 (1.47)	4.05 (1.23)	4.03 (1.23)	3.17 (0.97)
Vehicle Volume	Low (<540 vhp [vph?])	635	821	4.82 (1.47)	3.96 (1.21)	3.98 (1.21)	3.12 (0.95)
	Med (552-850 vph)	842	880	4.86 (1.48)	3.97 (1.21)	4.01 (1.22)	3.08 (0.94)
	High (936-1764 vph)	604	678	4.65 (1.42)	3.87 (1.18)	3.92 (1.19)	3.07 (0.94)

* Young = age appears to be between 14 to 64 yr old, Old = age appears to be over 65 yr old.

The 2001 *Traffic Control Devices Handbook* suggests that where walking speeds slower than a normal rate of 4.0 ft/s (1.2 m/s) are known to occur frequently and resources do not exist to undertake studies to establish the 15th percentile speed, a rate of 3.5 ft/s (1.07 m/s) may be applied (*121*).

La Plante and Kaeser (*116*) cited work done in 2004 by the City of Los Angeles Department of Transportation, where they conducted a number of pedestrian speed studies at locations where there were complaints of insufficient pedestrian clearance time, often in locations near senior centers. Their findings indicate that the average 15th percentile walking speed for reported problem intersections is 3.82 ft/s (1.16 m/s), and their staff has noted that the 2001 *Traffic Control Devices Handbook* (*121*) value of 3.5 ft/s (1.07 m/s) in the absence of specific studies appears to be appropriately conservative as an assumed walking speed.

In the *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians* report (*122*), an assumed walking speed of 2.8 ft/s (0.9 m/s) is recommended for less capable

(15^{th} percentile) older pedestrians due to their shorter stride, slower gait, and exaggerated "start-up" time before leaving the curb.

A study in Sweden (*123*) found that pedestrians aged 70 or older, when asked to cross an intersection very 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 (*124*) 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. They recommended as a design (15^{th} percentile) speed for elderly pedestrians of 4.0 ft/s (1.2 m/s) at intersections and 3.3 ft/s (1.0 m/s) at midblock crosswalks and intersections near senior housing and nursing homes.

A significant proportion (as much as 35 percent) of pedestrians – children, older pedestrians, and persons with disabilities – travel at a slower pace (*125*). 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 Institutes of Transportation Research (*126*) study of signalized crossing sites identified the walking speeds of "pedestrians with walking difficulty" (irrespective of age) including older persons, people with disability, 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 M-2. The data are divided between sites at signalized intersections and midblock signalized crossing sites. Comparison of data for the two types of locations indicates that crossing speeds are higher at signalized intersections, possibly due to a perception of less safe environment, especially due to turning vehicle conflicts. 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), which is commonly used for signal timing purposes, represents the 15^{th} percentile crossing speed, with the corresponding average crossing speed being 4.9 ft/s (1.5 m/s).

A similar Australian study (*127*) that investigated pedestrian movement characteristics at pedestrian-actuated midblock signalized crossings on four-lane undivided roads found the average crossing speed to be 4.7 ft/s (1.4 m/s) and the 15^{th} 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. The study also found that pedestrian speeds for the first half of the crossing were higher than speeds in the second half, and the average and 15^{th} percentile crossing speeds decrease with increased pedestrian flow rate. Also, crossing speeds and characteristics were similar during the weekdays and weekends.

TABLE M-2. Intersection Crossing Speeds of Pedestrians with and without Walking Difficulty (*126*).

	Average Speed, ft/s (m/s)	Standard Deviation	15th Percentile, ft/s (m/s)	50th Percentile, ft/s (m/s)	85th Percentile, ft/s (m/s)
Signalized Intersections					
Pedestrians with walking difficulty	4.42 (1.35)	0.25	3.74 (1.14)	4.23 (1.29)	5.34 (1.63)
Pedestrians without walking difficulty	5.58 (1.70)	0.50	4.27 (1.31)	5.25 (1.60)	6.69 (2.04)
All pedestrians	5.35 (1.63)	0.48	4.07(1.24)	5.12 (1.56)	6.43 (1.96)
Midblock Signalized Crossing					
Pedestrians with walking difficulty	4.23 (1.29)	0.28	3.28 (1.00)	4.30 (1.31)	4.99 (1.52)
Pedestrians without walking difficulty	4.75 (1.45)	0.22	4.04 (1.23)	4.72 (1.44)	5.45 (1.66)
All pedestrians	4.66 (1.42)	0.24	3.87 (1.18)	4.66 (1.42)	5.41 (1.65)

According to a study done in the United Kindgom in the 1980s, about 14 percent of adults over 15 years of age had physical, sensory, or mental handicaps (*128*). 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 disabled pedestrians are lower than the average walking speed assumed for the design of pedestrian crosswalk signal timing. For example, the walking speed with a walker is 2.07 ft/s (0.63 m/s) and with a cane or crutch is 2.62 ft/s (0.8 m/s) (*129*)**.** Table M-3 shows some average walking speeds for various disabilities and assistive devices.

TABLE M-3. Mean Walking Speeds for Disabled Pedestrians and Users of Various Assistive Devices (*129*).

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)

TCRP/NCHRP FIELD STUDY FINDINGS

One of the pedestrian characteristics collected during field studies conducted as part of the 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 can be determined. The walking speed associated with different roadway conditions and pedestrian characteristics is available from the data set. A variety of statistical analyses were used to better understand walking speed and to explore its relationship with the roadway environment and pedestrian characteristics.

Pedestrian Walking Speed by Age Groups

During the data reduction, the technicians assigned the pedestrian (or the dominant pedestrian of a group or cluster) into one of the following age categories:

- Child (ages 0-12),
- Teen (ages 13-18),
- Young adult (ages 19-30),
- Middle (ages 31-60),
- Older (ages greater than 60, but not classified as “elderly and/or physically disabled”),
- Elderly and/or physically disabled (crutches, self-propelled wheelchair, etc.), or
- Data could not be determined from video.

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

A total of 3155 pedestrians were recorded during this study. Of that value, 81 percent (2552 pedestrians) were observed as “walking.” The remaining 19 percent of the pedestrians (603 pedestrians) were observed to be running, both walking and running during the crossing, or using some form of assistance (e.g., skates, bikes, etc.). These 603 data points were not included in the following analyses. Also not included in the analyses were the 107 walking pedestrians whose age could not be estimated and, in later analyses, the 6 pedestrians whose gender could not be determined.

Table M-4 lists the walking speeds calculated for those pedestrians walking during the crossing by age groups. The cumulative distribution of the data for each age group is shown in Figure M-1. Figure M-1 also shows the 2003 *MUTCD* normal walking speed assumption (4 ft/s [1.2 m/s]) and the U.S. Access Board suggested value of 3 ft/s (0.9 m/s) for comparison.

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

- Younger: includes pedestrians between the ages of 13 and 60, and
- Older: includes pedestrians greater than 60 or elderly.

Table M-5 lists the walking speeds by age group and gender. The walking speed values for older pedestrians are lower than younger people. For young pedestrians, the 15^{th} percentile walking speed was 3.77 ft/s (1.15 m/s). Older pedestrians had a slower walking speed, with the 15^{th} percentile being 3.03 ft/s (0.92 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 M-2 illustrates the distribution of the walking speeds.

TABLE M-4. Walking Speed by Age Group.

Age Group (as estimated by technician)	Sample Size	Walking Speed, ft/s (m/s)	
		15th Percentile	50th Percentile
Elderly and/or physically disabled	15	2.75 (0.84)	3.38 (1.03)
Older (greater than 60, but not classified as elderly)	92	3.19 (0.97)	4.38 (1.34)
Middle (ages 31 to 60)	1464	3.82 (1.17)	4.75 (1.45)
Young (ages 19 to 30)	789	3.83 (1.17)	4.78 (1.46)
Teen (ages 13 to 18)	76	3.79 (1.16)	4.64 (1.42)
Child (0 to 12)	9	3.51 (1.07)	4.37 (1.33)
ALL PEDESTRIANS	**2445**	**3.82 (1.17)**	**4.78 (1.46)**

TABLE M-5. Walking Speed by Gender and Age Group.

Age Groups	Walking Speed, ft/s (m/s)		
	Sample Size	15th Percentile	50th Percentile
Male			
Younger	1434	3.75 (1.14)	4.78 (1.46)
Older	75	3.11 (0.95)	4.19 (1.28)
ALL	1509	3.67 (1.12)	4.75 (1.45)
Female			
Younger	890	3.79 (1.16)	4.67 (1.42)
Older	31	2.82 (0.86)	4.41 (1.35)
ALL	921	3.75 (1.14)	4.67 (1.42)
Both Genders			
Younger	2324	3.77 (1.15)	4.74 (1.45)
Older	106	3.03 (0.92)	4.25 (1.30)
ALL	**2430**	**3.70 (1.13)**	**4.72 (1.44)**

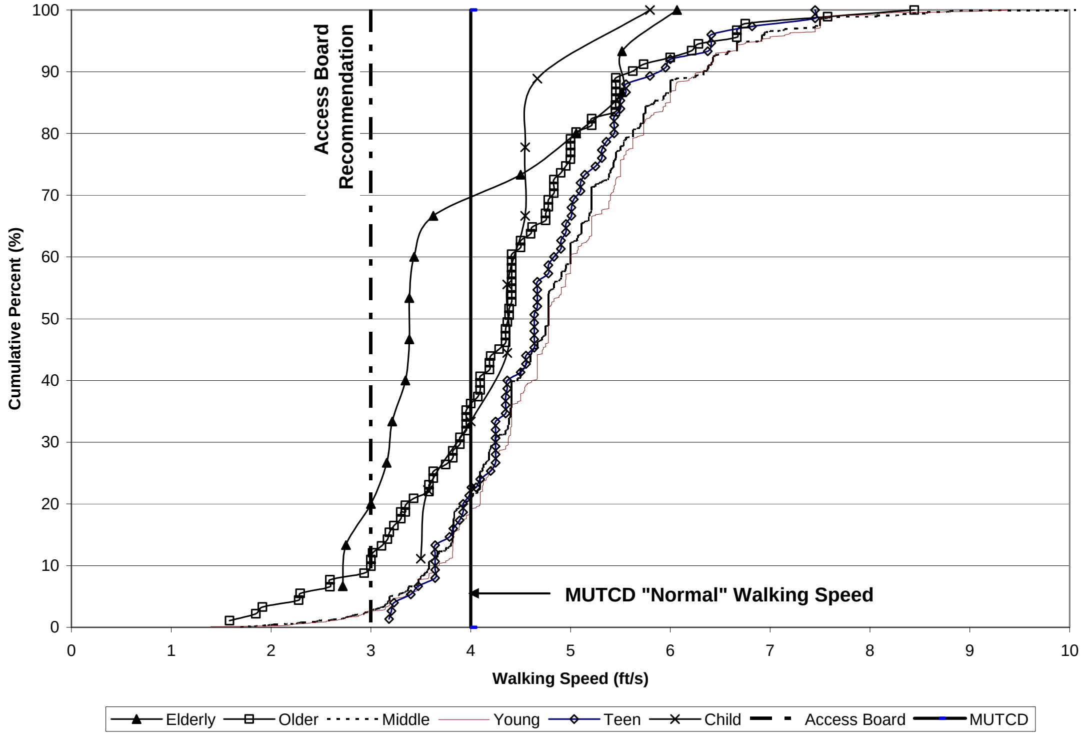


Figure M-1. Walking Speed Distribution by Age Group.

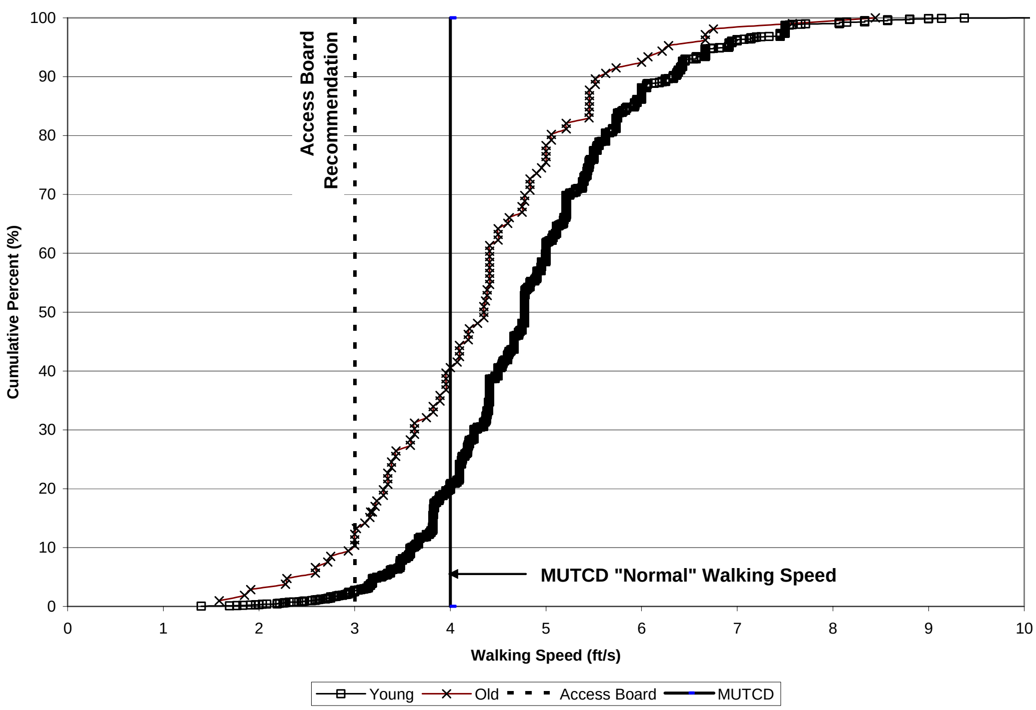


Figure M-2. Older than 60 (Old) and 60 and Younger than 60 (Young) Walking Speed Distribution.

Age Group Comparison

An F-test determined if the walking speeds by gender and age were statistically different. Table M-6 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 (0.92 m/s) for older 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 M-6. The young female group walked slightly slower (4.67 ft/s [1.42 m/s]) than the young male group (4.78 ft/s [1.46 m/s]).

TABLE M-6. F-Test Results for Gender and Age Group Walking Speed Comparisons.

Comparison	15th Percentile Walking Speed, ft/s (m/s)		F 15th	P	50th Percentile Walking Speed, ft/s (m/s)		F 50th	P	$F_{1,M-1,0.05}$
Male, Older & Younger	**3.11 (0.95)**	**3.75 (1.14)**	**22.59**	**0.0001**	**4.19 (1.28)**	**4.78 (1.46)**	**19.2**	**0.0001**	3.85
Female, Older & Younger	**2.82 (0.86)**	**3.79 (1.16)**	**24.8**	**0.0001**	4.41 (1.35)	4.67 (1.42)	1.78	0.1825	3.85
Both Age Groups Male & Female	3.67 (1.12)	3.75 (1.14)	2.91	0.0882	4.75 (1.45)	4.67 (1.42)	2.91	0.0882	3.84
Older Male & Female	3.11 (0.95)	2.82 (0.86)	2.67	0.1053	4.19 (1.28)	4.41 (1.35)	1.54	0.2174	2.91
Younger Male & Female	3.75 (1.14)	3.79 (1.16)	0.70	0.4029	**4.78 (1.46)**	**4.67 (1.42)**	**5.31**	**0.0213**	3.84
Both Genders Older & Younger	**3.03 (0.92)**	**3.77 (1.15)**	**35.25**	**0.0001**	**4.25 (1.30)**	**4.74 (1.45)**	**14.96**	**0.0001**	3.84

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

Statistical Evaluations of Available Variables

The number of older pedestrians (106 pedestrians) in the database was small compared to the number of younger pedestrians (2324 pedestrians); therefore, separate analyses were carried out for each of the younger and older pedestrian data sets. Table M-7 contains the result of the fit of the analysis of covariance (ANACOVA) model for the younger age group. The model considered:

- Number of pedestrians crossing together (Num Ped),
- Five-minute vehicle volume on major roadway around the time the pedestrian crossed (SV5),
- Treatment (Treat),
- Major speed limit,
- Presence of median refuge (Median Refuge),

- Crossing distance measured from curb to curb (Curb to Curb), and
- Gender.

The types of treatments studied included:

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

From Table M-7 it can be observed that the effects of the following variables are statistically significant at the level $\alpha = 0.05$:

- Num Ped,
- SV5,
- Treat,
- Major Speed Limit, and
- Median Refuge

The effects of Curb to Curb and Gender are not statistically significant at $\alpha = 0.05$. The R-square value is 0.28 and the adjusted R-square value is 0.27 for the fit in Table M-7.

TABLE M-7. Analysis of Covariance for Walking Speed for Younger Age Group.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	16	756.8034	47.3002	55.6742	<0.0001
Num Ped	**1**	**15.56567**	**15.5657**	**18.3214**	**<0.0001**
SV5	**1**	**7.70482**	**7.7048**	**9.0689**	**0.0026**
Treat	**8**	**273.92210**	**34.2403**	**40.3021**	**<0.0001**
Major Speed Limit	**3**	**117.19880**	**39.0663**	**45.9825**	**<0.0001**
Curb to Curb	1	1.98642	1.9864	2.3381	0.1264
Median Refuge	**1**	**10.28562**	**10.2856**	**12.1066**	**0.0005**
Gender	1	2.86497	2.8650	3.3722	0.0664
Error	2307	1960.0031	0.8496		
C. Total	2323	2716.8066			

*Note: Variables that are significant at $\alpha = 0.05$ are shown in bold.

Table M-8 contains the result of the fit of the ANACOVA model for the old age group. This table shows that only the effect of Treat is statistically significant at the level $\alpha = 0.05$. The effects of Major Speed Limit and Curb to Curb are statistically significant at $\alpha = 0.10$, but not at $\alpha = 0.05$. The R-square value from this analysis is 0.34 and the adjusted R-square value is 0.28. Remember that the old age group only had 106 data points as compared to the 2324 available for the young age group evaluations. Therefore, the findings shown in Table M-7 should be more reliable.

TABLE M-8. Analysis of Covariance for Walking Speed for Older Age Group.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	15	47.28705	3.1525	3.0587	<0.0001
Num Ped	1	0.173959	0.1740	0.1688	0.6822
SV5	1	0.632902	0.6329	0.6141	0.4353
Treat	**8**	**23.131439**	**2.8914**	**2.8054**	**0.0080**
Major Speed Limit	2	6.073761	3.0369	2.9465	0.0576
Curb to Curb	1	3.858643	3.8586	3.7438	0.0561
Median Refuge	1	0.267619	0.2676	0.2597	0.6116
Gender	1	2.476301	2.4763	2.4026	0.1246
Error	90	92.75960	1.0307		
C. Total	105	140.04665			

*Note: Variables that are significant at $\alpha = 0.05$ are shown in bold.

Comparison of Walking Speeds by Type of Pedestrian Treatment

A multiple comparison procedure was employed to find out which pair of treatments is different based on the least-squares means from the models in Tables M-7 and M-8. Tables M-9 and M-10 summarize the result of the multiple comparisons for young age group and old age group, respectively. It can be concluded that for young pedestrians:

- The predicted walking speed with Flag is significantly higher than that of others (flags are significantly different from all other treatments).
- The predicted walking speeds for HiVi and Msig are lower than that of Flag but higher than that of Inst, Refu, Half, Hawk, and OfPb.
- The predicted walking speed for OfPa is lower than that for Flag and Msig, but higher than that for Refu, Half, Hawk, and OfPb.

It can be concluded that for old pedestrians:

- The predicted working speeds for OfPb, Flag, and Msig are higher than that of Hawk.

TABLE M-9. Result of Tukey's HSD Multiple Comparisons for Treatment Based on the Model in Table M-7.

Level						Least Sq Mean
Flag	A					5.2980124
HiVi		B	C			4.8004532
Msig		B				4.7897346
OfPa			C	D		4.4124009
InSt				D	E	4.0960485
Refu					E	3.9600476
Half					E	3.9349713
Hawk					E	3.9212409
OfPb					E	3.8768585

*Levels not connected by same letter are significantly different.

TABLE M-10. Result of Tukey's HSD Multiple Comparisons for Treatment Based on the Model in Table M-8.

Level			Least Sq Mean
OfPb	A		5.6607761
Flag	A		4.9280171
InSt	A	B	4.3144790
Msig	A		3.9734799
Half	A	B	3.8372235
HiVi	A	B	3.8177563
Refu	A	B	3.3013557
OfPa	A	B	2.2948175
Hawk		B	0.9268298

*Levels not connected by same letter are significantly different.

Another approach determined if those sites with pedestrian treatments that show a red ball indication to the driver have a different walking behavior. Table M-11 lists the walking speed by whether a treatment shows a red indication to the driver.

Table M-12 lists the results of the F-tests conducted to determine if walking speed is affected by whether the pedestrian treatment does or does not show a red indication. For the entire data set, no difference in walking speed was observed (see bottom row of numbers in Table M-12). A difference in walking speed for older users (both male and female) was observed for the 15th percentile walking speed. Surprising, the location where the walking speed was higher was different for the male and female groups. The old female group walked faster at locations with the red indications (4.2 ft/s [1.28 m/s] as compared to 3.17 ft/s [0.97 m/s]), while the old male group walked slower (2.59 ft/s [0.79 m/s]) at a red site as compared to (3.30 ft/s [1.0 m/s] at a non-red site).

TABLE M-11. Walking Speed by Treatment Category, Gender, and Age Groups.

Age Group	Walking Speed, ft/s (m/s)					
	Male			Female		
	Number of Points	15th Percentile	50th Percentile	Number of Points	15th Percentile	50th Percentile
Red Indication (e.g., Half-Signal, HAWK, Midblock Signal)						
Younger	385	3.82 (1.17)	4.75 (1.45)	302	3.85 (1.17)	4.75 (1.45)
Older	20	2.59 (0.79)	4.19 (1.28)	10	4.20 (1.28)	5.00 (1.53)
Non-Red Indication (all other treatments included in study)						
Younger	1056	3.82 (1.17)	4.78 (1.46)	592	3.82 (1.17)	4.75 (1.45)
Older	55	3.30 (1.01)	4.35 (1.33)	21	3.17 (0.97)	3.95 (1.20)

TABLE M-12. F-Test Results for Treatment Category, Gender and Age Group Walking Speed Comparisons.

Comparison	15th Walking Speed, ft/s (m/s)		F 15th	P	50th Walking Speed, ft/s (m/s)		F 50th	P	$F_{1,M-1,0.05}$
Male Younger Red to Non-Red	3.82 (1.17)	3.82 (1.16)	0.00	1.0000	4.75 (1.45)	4.78 (1.46)	0.21	0.6468	3.85
Male Older Red to Non-Red	**2.59 (0.79)**	**3.30 (1.01)**	**4.80**	**0.0316**	4.19 (1.28)	4.35 (1.33)	0.24	0.6257	3.98
Female Younger Red to Non-Red	3.85 (1.17)	3.82 (1.17)	0.18	0.6715	4.75 (1.45)	4.75 (1.45)	0.00	1.0000	3.85
Female Older Red to Non-Red	**4.20 (1.28)**	**3.17 (0.97)**	**9.76**	**0.0039**	**5.00 (1.53)**	**3.95 (1.20)**	**10.14**	**0.0034**	4.17
Both Gender Red to Non-Red	3.80 (1.16)	3.80 (1.16)	0.00	1.0000	4.74 (1.45)	4.75 (1.45)	0.38	0.5377	3.85

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

Comparison of Walking Speed between Initial Crossing Stage and Second Crossing Stage When a Median is Present

The time to cross the street was split into two portions when a median was present. The time to cross was measured from the initial curb to the center of the median and then from the center of the median to the far curb. Any delay time in the median due to waiting for an adequate gap was not included in the walking speed calculations. Table M-13 lists the walking speeds for sites with medians.

Table M-14 lists the results of the F-test that compared the walking speeds between the two portions of pedestrian crossing. The values shown in bold indicated that there is a statistical difference between the walking speeds for different portions of a crossing. For example, Table M-14 shows that young males at the 15th percentile walking speed walked faster in the first portion of the crossing (3.95 ft/s [1.2 m/s]) as compared to the second portion (3.58 ft/s [1.09 m/s]). The 19 old females included in the study set, however, walked statistically slower in the first portion of the crossing (1.65 ft/s [0.5 m/s]) as compared to the second portion (2.71 ft/s [0.83 m/s]).

TABLE M-13. Walking Speed by Crossing Stage, Gender, and Age Groups for those Sites with Medians.

Age Group	Walking Speed, ft/s (m/s)					
	Male			Female		
	Number of Points	15th Percentile	50th Percentile	Number of Points	15th Percentile	50th Percentile
	Initial Crossing Stage (curb to median)					
Younger	955	3.95 (1.20)	5.00 (1.53)	561	3.59 (1.09)	4.78 (1.46)
Older	50	3.16 (0.96)	4.17 (1.27)	19	1.65 (0.50)	1.90 (0.58)
	Second Crossing Stage (median to curb)					
Younger	955	3.58 (1.09)	4.78 (1.46)	561	3.58 (1.09)	4.71 (1.44)
Older	50	2.75 (0.84)	4.10 (1.25)	19	2.71 (0.83)	3.65 (1.11)
	Entire Crossing (curb to curb)					
Younger	962	3.95 (1.20)	4.78 (1.46)	572	3.82 (1.17)	4.75 (1.45)
Older	50	3.30 (1.01)	4.19 (1.28)	19	2.75 (0.84)	3.62 (1.10)

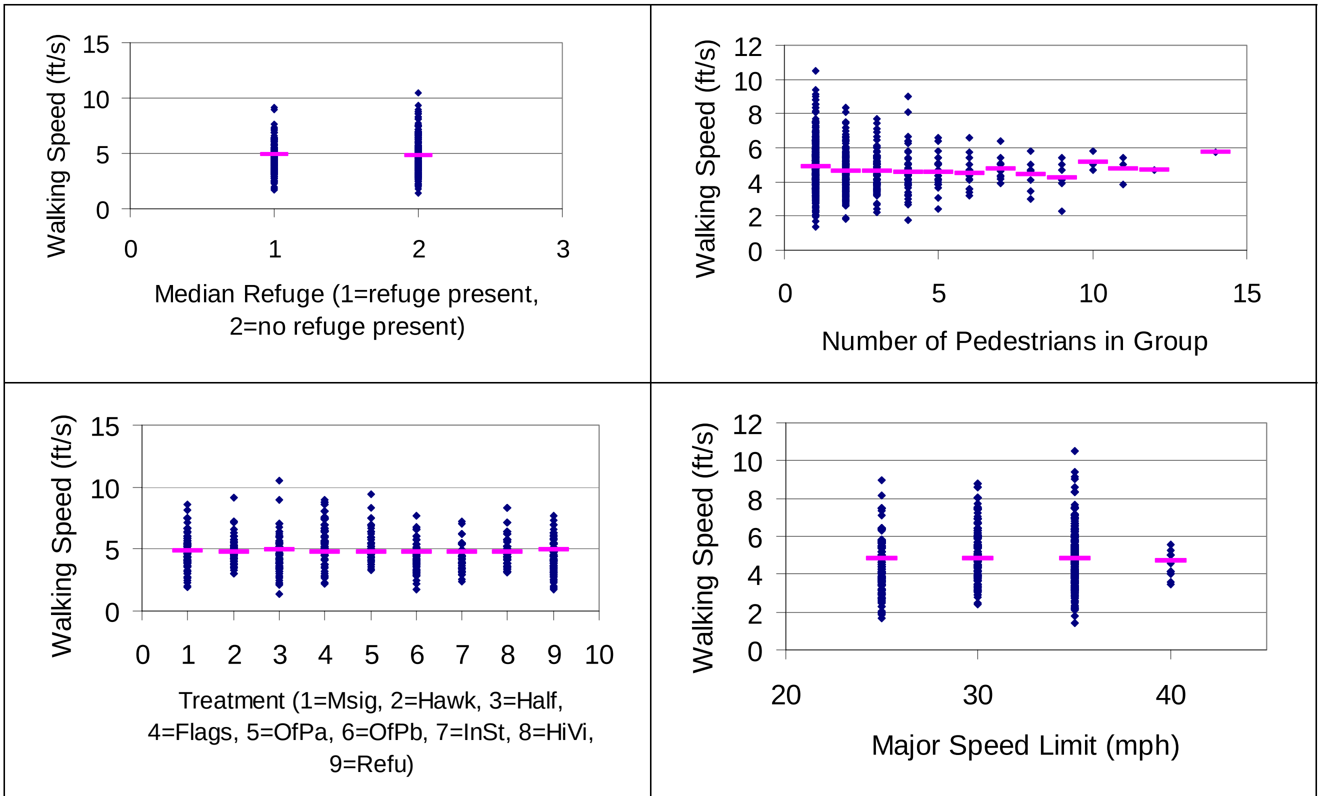
TABLE M-14. F-Test Results for Crossing Stage, Gender, and Age Group Walking Speed Comparisons.

Comparison	15th Walking Speed, ft/s (m/s)		F 15th	P	50th Walking Speed, ft/s (m/s)		F 50th	P	$F_{1,M-1,0.05}$
Male Younger Initial to Second	**3.95 (1.20)**	**3.58 (1.09)**	**29.51**	**0.0001**	**5.00 (1.53)**	**4.78 (1.46)**	**10.43**	**0.0013**	3.85
Male Older Initial to Second	3.16 (0.96)	2.75 (0.84)	2.02	0.1584	4.17 (1.27)	4.10 (1.25)	0.06	0.8070	2.91
Female Younger Initial to Second	3.59 (1.09)	3.58 (1.09)	0.01	0.9204	4.78 (1.46)	4.74 (1.45)	0.66	0.4167	3.85
Female Older Initial to Second	**1.65 (0.50)**	**2.71 (0.83)**	**10.9**	**0.0021**	**1.90 (0.58)**	**3.65 (1.11)**	**28.1**	**0.0001**	4.10

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

Practical Differences

While Table M-7 shows several variables with a statistical significant difference, there may not be a practical difference. As an example, Figure M-3 shows the plots of individual walking speed by selected crossing characteristics. The diamonds represent individual walking speeds, while the bars represent the average walking speed. For comparisons, the difference between a younger pedestrian and an older pedestrian when crossing a 50-ft (15.3 m) pavement was calculated. An older pedestrian would use 1.2 seconds more to complete the crossing, resulting in a 10 percent difference in crossing time between the older and younger pedestrian.



NOTE: 1 ft/s = 0.305 m/s

Figure M-3. Walking Speed by Crossing Characteristic.

The average walking speed when a median refuge island is present is 4.87 ft/s (1.48 m/s), while the average walking speed when the median refuge island is not present is 4.80 ft/s (1.46 m/s). When crossing a 50-ft (15.2 m) pavement, the pedestrians at the median refuge island sites would take 10.27 seconds, while at the sites without a refuge island the pedestrian crosses in 10.42 seconds. The crossing time difference is only 0.15 seconds, for a 1.5 percent difference.

A review of the average walking speed per major road speed limit shows that the average walking speed is essentially the same for 25, 30, and 35 mph (40, 48, and 56 km/h) major road speed limits (essentially 4.83 ft/s [1.47 m/s]). The walking speed for the 13 pedestrians at the 40 mph (64 km/h) site was 4.71 ft/s (1.44 m/s), which would result in a 2 percent increase in crossing time (0.2 second for a 50-ft [15.2 m] pavement).

Reviewing the average crossing speeds for the different types of treatments reveals that the greatest average walking speed difference is between sites with a median refuge island (4.92 ft/s [1.50 m/s]) and high-visibility markings (4.76 ft/s [1.45 m/s]). The crossing time difference for a 50-ft (15.2 m) pavement would be 0.4 second, representing a 4 percent difference.

The number of pedestrians in a group appears to be the only characteristic that may have a practical difference in addition to pedestrian age. When only one pedestrian is crossing, the average crossing speed is 4.92 ft/s (1.50 m/s). When two pedestrians are crossing, the average crossing speed is 4.65 ft/s (1.42 m/s), which represents a 5.5 percent difference in crossing time

(0.6 second) for a 50-ft (15.2 m) pavement. For the 16 groups of 6 pedestrians, the difference in crossing time for a 50-ft (15.2 m) pavement as compared to the crossing time for an individual is 0.9 second, for a 9 percent difference.

COMPARISON OF TCRP/NCHRP FINDINGS WITH PREVIOUS WORK

As documented in the initial section, several studies have examined walking speed. Most of the studies 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* [*130*].)

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 M-4 summarizes the 15th percentile findings from several of the studies. It also includes key characteristics of the study, such as whether the data reflect old or young pedestrians. As shown in Figure M-4, previous work has identified or recommended walking speeds as slow as 2.2 ft/s (0.7 m/s) and as fast as 4.27 ft/s (1.3 m/s) for a 15th percentile value. Two studies with databases known to include over 2000 pedestrian crossings are the 1996 Knoblauch et al. study (*118*) and this TCRP/NCHRP study. Table M-15 summarizes the findings for young, old, and all pedestrians from these two studies.

TABLE M-15. Walking Speed by Age Groups for Knoblauch et al. (*118*) and TCRP/NCHRP Studies.

Age Group	Walking Speed, ft/s (m/s)					
	Knoblauch			TCRP/NCHRP		
	Number of Points	15th Percentile	50th Percentile	Number of Points	15th Percentile	50th Percentile
Younger	2081	4.02 (1.23)	4.79 (1.46)	2335	3.77 (1.15)	4.74 (1.45)
Older	2378	3.10 (0.95)	3.94 (1.20)	106	3.03 (0.92)	4.25 (1.30)
All	4459*	3.53* (1.08)	4.34* (1.32)	2441	3.70 (1.13)	4.72 (1.44)

*Calculated using values provided in Knoblauch et al. paper.

Based upon their findings, Knoblauch et al. suggested a value of 4.0 ft/s (1.2 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 Kaeses (*116*) in a September 2004 *ITE Journal* article recommended 3.5 ft/s (1.07 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.

The TCRP/NCHRP study had a similar number of young pedestrians within the data set as compared to the 1996 study (over 2000 pedestrians). The TCRP/NCHRP study, however, found a slower walking speed (3.77 ft/s [1.15 m/s], as compared to 4.02 ft/s [1.23 m/s]). Therefore, the findings from this TCRP/NCHRP study do not support the suggestion of a 4.0 ft/s (1.2 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 1996 study found 3.53 ft/s (1.08 m/s). Based upon the larger number of older pedestrians included in the 1996 study, a recommendation of 3.5 ft/s (1.07 m/s) for the timing of a traffic signal design appears to be 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.

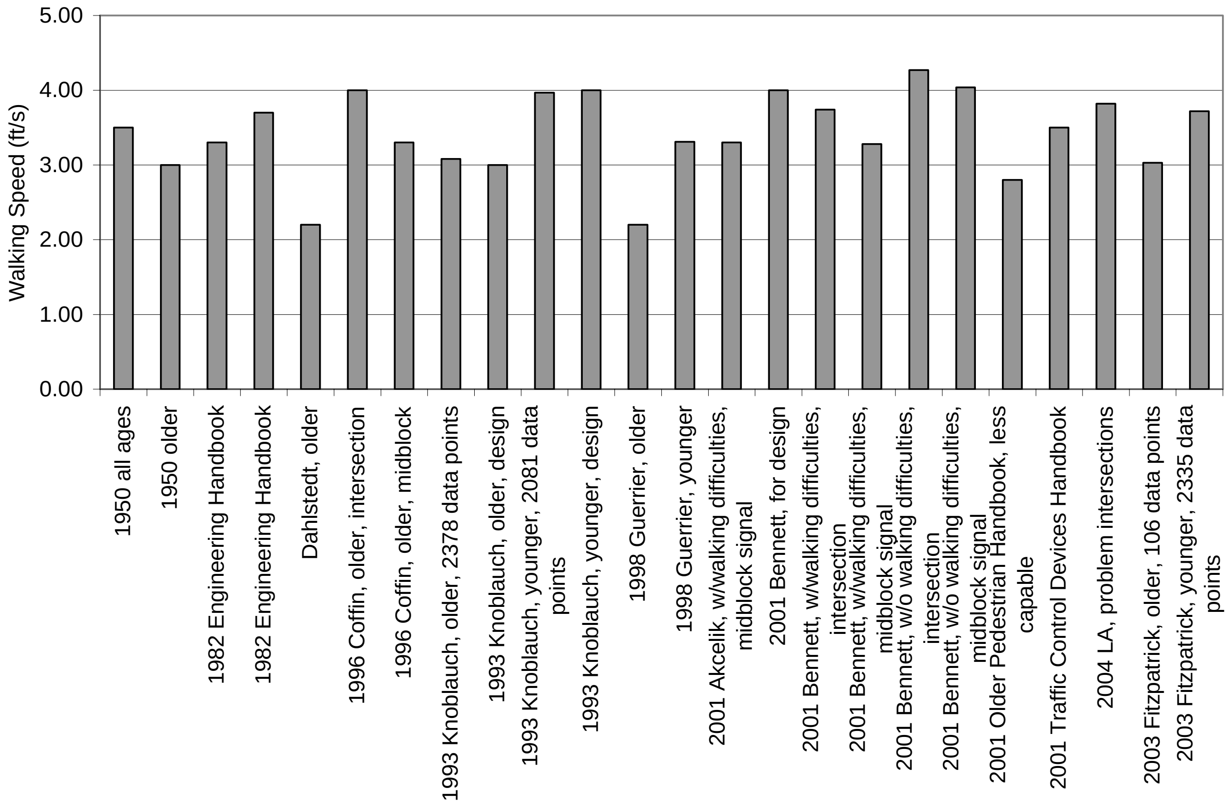


Figure M-4. Comparison of Findings from Previous Studies for 15th Percentile Walking Speed (Labels Contain Year of Study, Authors or Abbreviation of Title, and Characteristics of Study if Relevant).

FUTURE PROJECTIONS

A concern with selecting values based on historical data is whether those values will change over time and if so how much. Because there is a significant difference in walking speeds between pedestrians younger than 60 and pedestrians older than 60, the anticipated shift in demographics will affect average crossing times. Table M-16 shows the representative 15th percentile walking speed for the 15 years old and above population using:

- Population projections from U.S. Census (*131*),
- The 15th percentile younger population walking speed from the TCRP/NCHRP study (since it has the most recent data), and
- The 15th percentile older population walking speed from Knoblauch et al. study (since they had a much larger older population sample size).

The percentage of each population group is used to calculate a design walking speed value based on the 15th percentile walking speeds for each group. As shown in Table M-16, the proportionally weighted walking speed would be 3.63 ft/s (1.11 m/s) in 2005, 3.56 ft/s (1.09 m/s) in 2025, and 3.56 ft/s (1.09 m/s) in 2045.

TABLE M-16. Representative 15th Percentile Walking Speed for Future Years.

Year	Age Group	Percent of Population Group*	Adjusted Percent of Population Group	15th Percentile Walking Speed** ft/s (m/s)
2005	15 to 59	62	78	3.77 (1.15)
	Over 60	17	22	3.10 (0.95)
	Total	80	100	**3.63 (1.11)**
2025	15 to 59	55	69	3.77 (1.15)
	Over 60	25	31	3.10 (0.95)
	Total	80	100	**3.56 (1.09)**
2045	15 to 59	55	68	3.77 (1.15)
	Over 60	25	32	3.10 (0.95)
	Total	80	100	**3.56 (1.09)**

*Population projects from U.S. Census website (*131*).
**The 15th percentile walking speed for the 15 to 59 age group is from the TCRP/NCHRP study and for the 60 and over age group from the Knoblauch et al. study (due to greater sample size).

SUMMARY AND CONCLUSIONS

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 who walk slower than normal or pedestrians who use 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 (0.7 to 1.3 m/s). In 2002, the Public Rights-of-Way Access Advisory Committee released their draft guidelines for public comment and recommended a universal maximum pedestrian walking speed of 3.0 ft/s (0.9 m/s).

The TCRP/NCHRP study found the following:

- 15th percentile walking speed for younger pedestrians is 3.77 ft/s (1.15 m/s),
- 15th percentile walking speed for older pedestrians is 3.03 ft/s (0.92 m/s),
- There is a statistical difference in walking speeds between older (60 years old and greater) and younger pedestrians (less than 60 years old), and
- There is a statistical difference in walking speed between the first half and second half of the crossing when a median is present for young males and old females, with young males walking faster in the first half and old females walking faster in the second half.

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

- 3.5 ft/s (1.07 m/s) walking speed for general population, and
- 3.0 ft/s (0.9 m/s) walking speed for older or less able population.

APPENDIX N

GAP ACCEPTANCE

INTRODUCTION

This Appendix describes the efforts to evaluate pedestrian gap acceptance as a part of the TCRP/NCHRP project. The objectives of this portion of the project were:

- To determine the characteristics of available and accepted gaps at each study site,
- To identify behavioral patterns and statistical trends associated with the gap acceptance data, and
- To compare the accepted gaps at each site with the corresponding critical gap.

A crossing maneuver involves the pedestrian making a decision to accept a particular gap in the traffic stream. The pedestrian must make a "yes/no" decision for each gap in traffic that occurs; either the pedestrian accepts the gap or rejects it. The "yes/no" nature of the decision gives gap acceptance a unique set of conditions that can be utilized in analysis. Evaluation of actual accepted and rejected gaps can employ a logistic (or logit) transformation. The evaluation provides the probability of accepting a gap of a certain length. In this way, the accepted gap for selected percentiles of the pedestrian population can be determined. The logit model was used to determine accepted gaps at several sites within this research project.

BACKGROUND

A thorough review of pedestrian gap acceptance requires a familiarity with the various kinds of gaps that are encountered. There are gaps defined by the characteristics of the site (referred to as adequate gaps and critical gaps) and gaps dependent on the conditions present at the time a pedestrian attempts to cross (referred to as available, accepted, and rejected gaps). The available gap is the gap present for a pedestrian. If the pedestrian accepts the available gap (i.e., crosses the street within that gap), then it is an accepted gap; otherwise, it is a rejected gap. The adequate gap for a site is determined by dividing the crossing distance by the walking speed and adding an appropriate start-up time. However, while an approximate walking speed is used for such a calculation, the actual walking speed for each pedestrian will vary, largely depending on age and physical ability, along with the conditions present at the site. The Highway Capacity Manual (*HCM*) defines the critical gap as "the time in seconds below which a pedestrian will not attempt to begin crossing the street. If the available gap is greater than the critical gap, it is assumed that the pedestrian will cross, but if the available gap is less than the critical gap, it is assumed that the pedestrian will not cross" (*109*). The term "adequate gap" is used in the *MUTCD* and is assumed to be the same as the critical gap in the *HCM*. A question is whether the gaps being accepted at sites are, in fact, less than the calculated critical (adequate) gap. An analysis of the actual accepted and rejected gaps can reveal whether the critical gap is reasonable.

That the determination of the critical gap for a crossing maneuver requires a value for walking speed indicates the strong relationship between walking speed and gap acceptance. The value chosen for an approximate walking speed at a given site determines the length of a critical gap. If the assumed walking speed is unrealistic, so is the critical gap. Conversely, if observed behavior shows that accepted gaps are equal to or less than the calculated critical gaps, the chosen value of walking speed is validated for that site. The following analysis of observed gap acceptance behavior utilized results from the portion of this project investigating appropriate walking speeds. Detailed discussion and findings on recommended values of walking speed can be found in Appendix M.

The ability of various groups of pedestrians to select appropriate gaps depends on their ability to determine the speed of approaching vehicles and the time necessary to cross the street. This ability varies primarily with age and physical limitations. Oxley et al. (*132*) conducted a study to investigate age differences in the ability to choose safe time gaps in traffic in a simulated road-crossing task as well as some of the factors involved in such judgments. The first experiment investigated age differences in gap selection during road-crossing tasks in a simulated traffic environment in which time gap and vehicle speed were systematically varied. Participants were asked to make decisions under time pressure, and consequently, mean decision times were much lower than in the on-road observational studies. The authors considered that perhaps, under time constraints decisions are made primarily on the most immediately available and most easily accessible information, which was distance of the vehicle. Judgments about speed require information about vehicles over time and this may require longer time to process with advancing age. It is, therefore, possible that if given more time to inspect the stimulus display and to make a crossing decision, participants are more likely to base their decisions on the time gap (integrating distance and speed) rather than the distance alone. This may be especially important for the oldest participants, leading to less risky crossing decisions. These possibilities were explored in the second experiment by examining the effect of different presentation times of virtual traffic scenes on the ability to judge safe gaps in traffic.

As it turned out, presentation time made little difference to the proportion of acceptance responses of the young group. Rather, distance and, to a lesser extent, time gap seemed to influence their decision to cross. That is, even at short presentation times, young participants were more likely to cross when distances were longer even though time gaps did not vary, but they also accepted gaps more often when the reverse was true. Thus, younger adults were able to process both distance and speed of vehicles in very short periods of time, even though they primarily based their crossing decisions on vehicle distance. For the middle and oldest age categories, these observations were somewhat similar but depended more on longer observation times. Thus, older pedestrians are more likely to make incorrect decisions about the length of an adequate gap if compelled to make a quick decision, which leads to higher rates of crashes, injuries, and fatalities in older pedestrians. Therefore, the ability to correctly estimate the length of an adequate gap at a particular site can improve pedestrian safety at that site.

DATA COLLECTION

For the TCRP/NCHRP project, a field study was conducted that observed pedestrian crossing behavior at 43 sites in seven states. During the field study, researchers made a video recording of the pedestrian activity during the generally 4-hour study period for each site. After the in-field work was completed, technicians reviewed the video from each site to observe all pedestrian crossings and record characteristics of each crossing maneuver. For gap acceptance analysis, the time each pedestrian arrived at the crossing and the time each vehicle entered the crosswalk were recorded. For vehicles that entered the crosswalk, their travel lane and stopping behavior were recorded. The stopping behavior of each vehicle was categorized by whether that vehicle stopped, slowed down, or should have stopped but continued through the crosswalk. All of the observed characteristics were recorded on data sheets and used to create an electronic master database for storage and reduction of the data. The length of each gap was then calculated from the differences between the arrival times of two consecutive vehicles, as shown in Figure N-1.

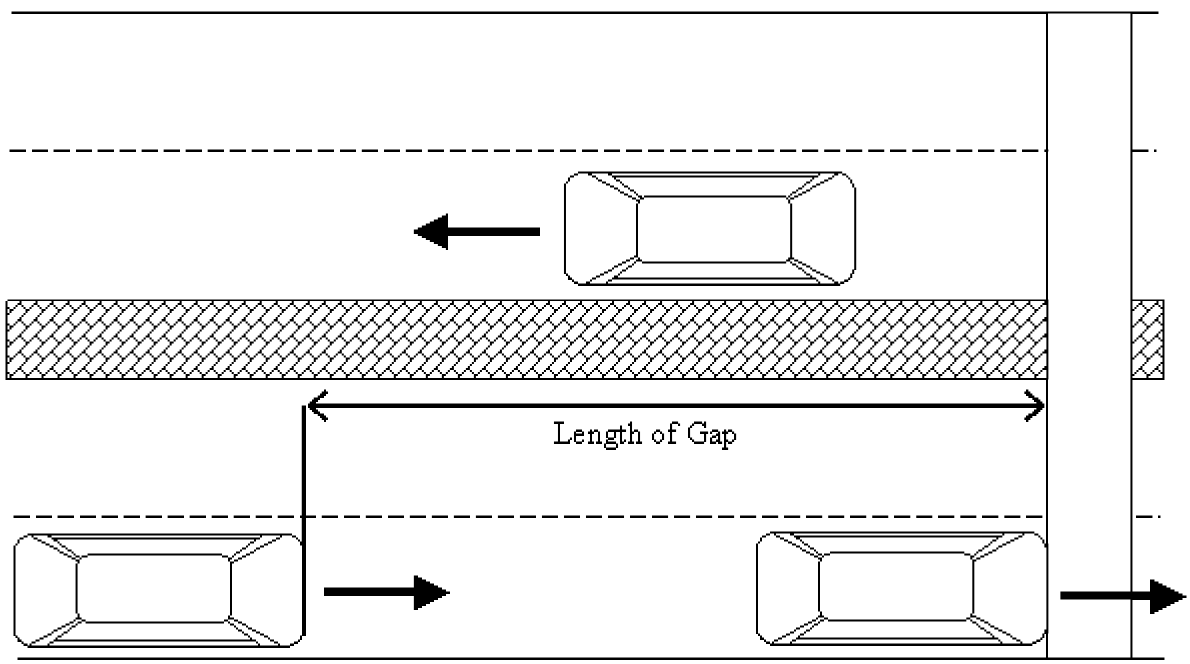


Figure N-1. Definition of Gap Length.

DATA REDUCTION

A review of the master database revealed that there were 45 approaches that had at least one crossing event with a vehicle that passed through the approach during that event (i.e., at least one gap was rejected by the pedestrian). The pedestrian and vehicle arrival data collected from the video for the crossing events on each approach were used to compile a gap acceptance database in the format shown in Figure N-2.

Figure N-2 provides data for one-half of a crossing on a divided roadway. The gap acceptance data were organized so that each direction of vehicular traffic and each direction of pedestrian traffic were in separate categories; thus, a study site could have as many as four sets of data in the database (two directions of vehicular traffic for each of two directions of pedestrian traffic). In the sample shown in Figure N-2, the pedestrian arrival time would be equivalent to the time a westbound pedestrian walks to the edge of the median to cross the second (southbound) portion of the roadway. After the pedestrian approaches the edge of the median, nine vehicles pass through the crosswalk at intervals ranging from 1 to 3 seconds; the waiting pedestrian rejects those gaps as too short. The pedestrian then determines that the available gap between the ninth and tenth vehicles is sufficient to complete the crossing, accepts the gap, and crosses the street. The tenth vehicle slows down upstream of the crosswalk to allow the pedestrian to cross, then passes through the crosswalk 6 seconds after the ninth vehicle. Thus, the accepted gap for the pedestrian in Figure N-2 was 6 seconds.

Ped Number	Ped Arrive (mm.ss)	Veh Time (mm.ss)	Gap (sec)	Veh Lane	Veh Dir	Veh Action*	Ped Action*
6	56.27	56.29	2	4	SB	M	R
6		56.31	2	4	SB	M	R
6		56.33	2	4	SB	M	R
6		56.34	1	3	SB	M	R
6		56.37	3	4	SB	M	R
6		56.38	1	4	SB	M	R
6		56.39	1	3	SB	M	R
6		56.41	2	4	SB	M	R
6		56.42	1	4	SB	M	R
6		56.48	6	3	SB	SL	A

*Codes: Veh Action -- M(oving), SL(owing), ST(opping)
Ped Action -- A(ccept), R(eject)

Figure N-2. Sample of Gap Acceptance Data.

The resulting database contained 3632 gaps observed by 605 individual pedestrians or groups of pedestrians, of which 3027 gaps were rejected and 605 were accepted. Within the 3027 rejected gaps, there were 572 gaps of zero duration. These were caused by a vehicle arriving at the crosswalk at the same time as a pedestrian, or by two vehicles arriving at the crosswalk traveling side-by-side. These zero-duration gaps were removed from the database prior to analysis, leaving 2455 rejected gaps, or 3060 total gaps. An additional review of the data set revealed that 11 approaches had more than 20 pedestrians crossing. The evaluations focused on those 11 approaches. Table N-1 lists the characteristics for the 11 approaches included in the evaluation.

TABLE N-1. Characteristics for Each Approach.

Site	Approach	Treatment*	Number of Pedestrians	Number of Gaps	Crossing Distance (ft)
CA-LA-2	NB 1/SB 2	OfPa	34	150	34
CA-LA-2	NB 2/SB 1	OfPa	32	241	38
CA-SM-2	NB 1/SB 2	Refuge	40	137	30
CA-SM-2	NB 2/SB 1	Refuge	30	125	30
CA-SM-3	NB 1/SB 2	Refuge	31	132	30
CA-SM-3	NB 2/SB 1	Refuge	29	170	30
MD-PG-1	NB 2/SB 1	Refuge	21	521	35
MD-TN-1	NB	OfPb	22	124	46
MD-TN-1	SB	OfPb	34	232	46
UT-SL-2	NB	OfPb	22	105	54
WA-KI-3	EB	Flag	22	61	45
ALL Approaches where a Pedestrian Made a Gap Decision		**N/A**	**605**	**3060**	**N/A**

*OfPa = overhead flashing beacon with passive detection
OfPb = overhead flashing beacon with push button detection and flags
Refuge = refuge island is primary treatment at site
Flag = flags

ANALYSIS

The analysis was comprised of 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 gaps size for a proportion of the crossing population.

Behavioral Analysis

There are some specific behavioral patterns that have an effect on the way the 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 N-3. 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 and are distributed between both lanes. In the “rolling gap” scenario, the pedestrian would begin the crossing maneuver when the acceptable gap 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, as in Figure N-4. 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, as shown in Figure N-5. 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 N-3. 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.”

One conclusion that can be drawn from this analysis is that pedestrians are often creative and adaptable to conditions. A pedestrian who feels he or she has waited an inordinate amount of time for all lanes to clear, particularly one who is familiar with the crossing, will adjust his or her perception of what is an acceptable gap. In this study, that revised perception often is focused on only one lane at a time.

This behavior is not captured in most designs; the usual assumption is that the pedestrian waits for all lanes to clear before crossing. While this assumption is not always realistic, it provides a more conservative design. Pedestrians who are comfortable with “rolling gaps” may voluntarily accept them. However, to minimize the potential for crashes and injuries, designs should not encourage the acceptance of “rolling gaps” by pedestrians who are not comfortable with them and would otherwise reject them.

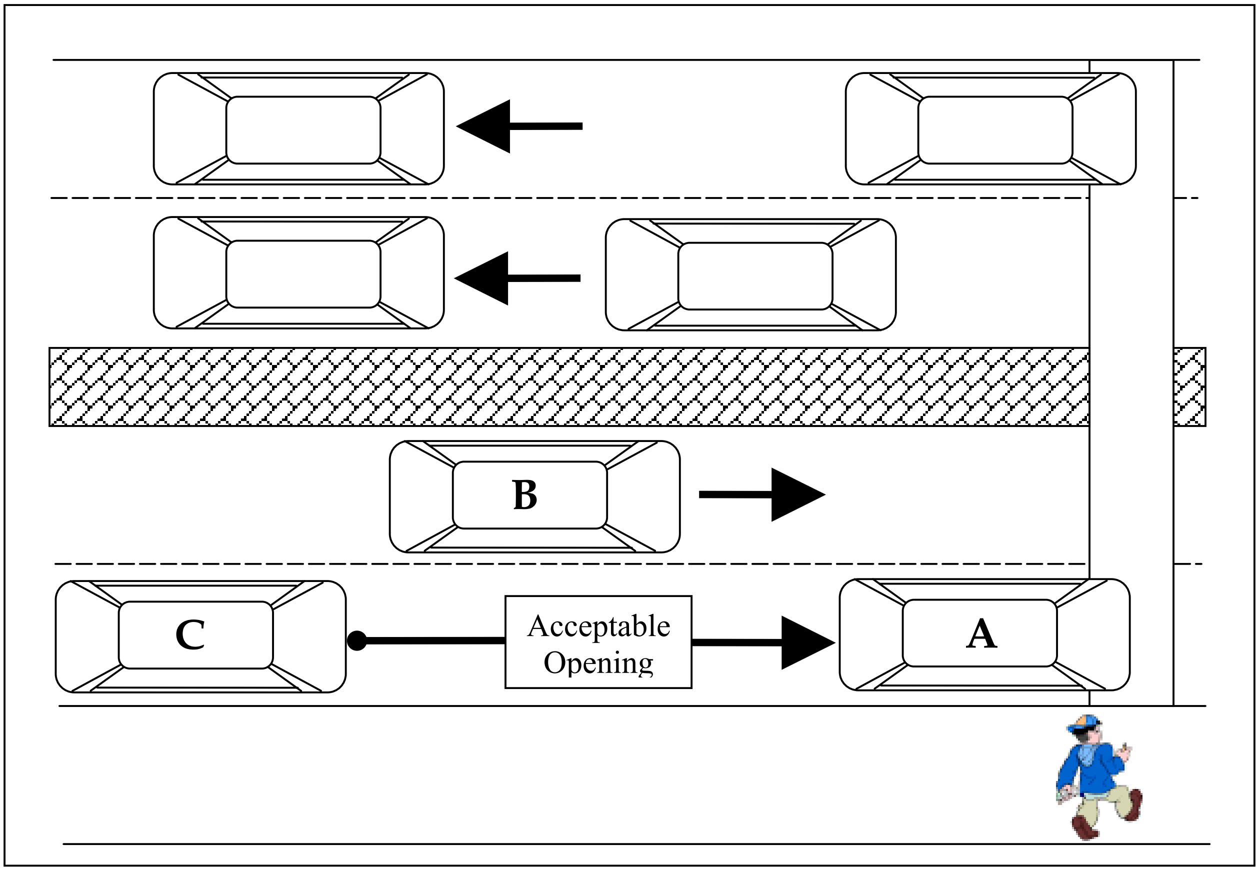


Figure N-3. Pedestrian Waiting to Cross at Crosswalk with High Traffic Volumes.

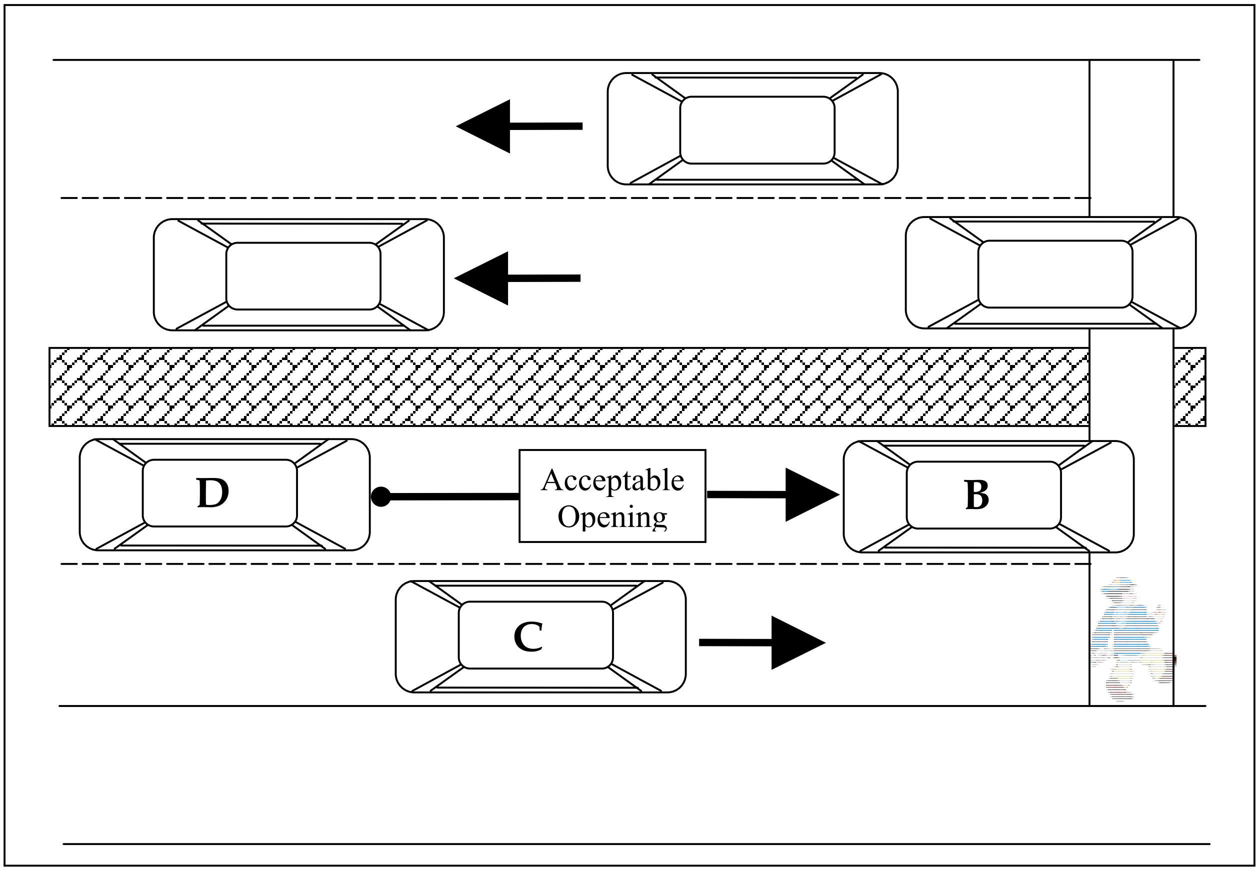


Figure N-4. Pedestrian Crossing First Lane of Approach Using a "Rolling Gap."

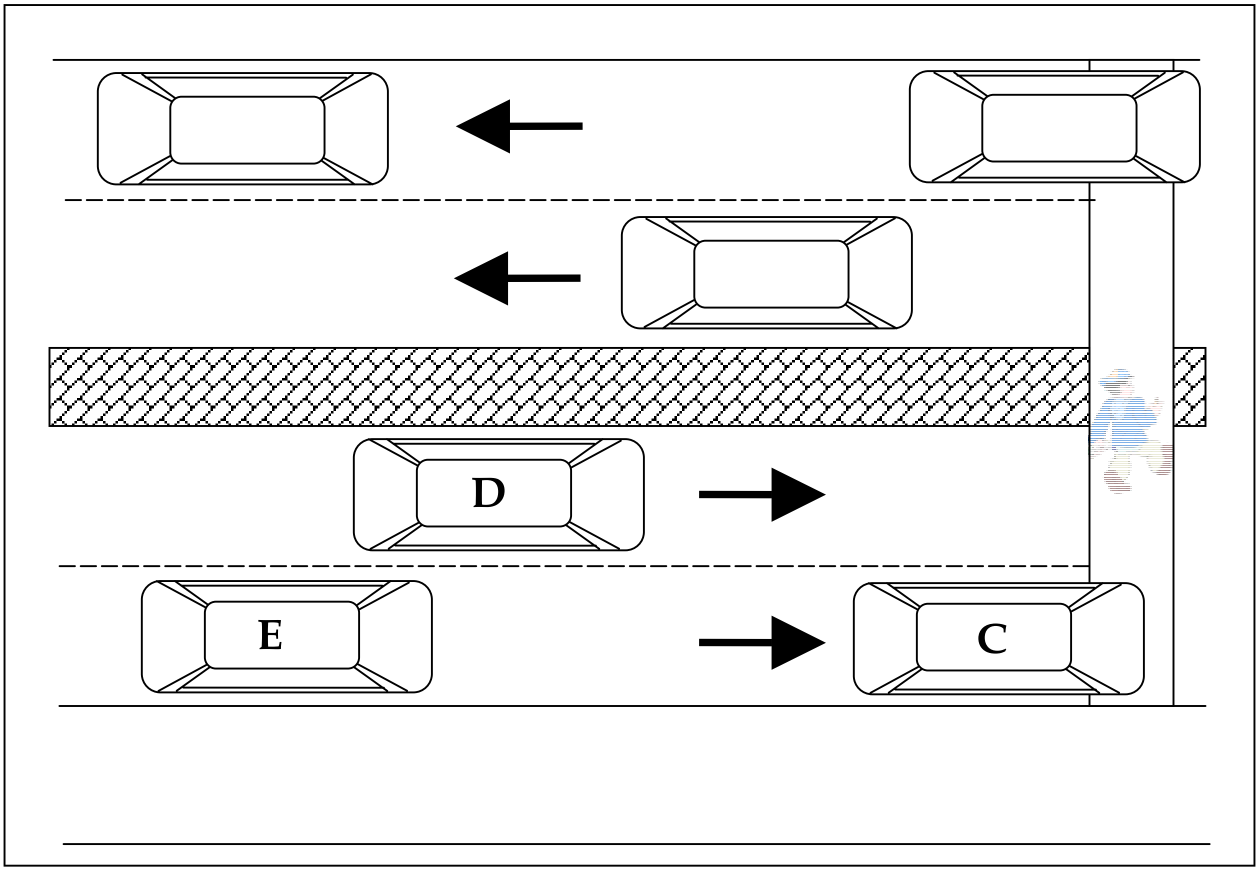


Figure N-5. Pedestrian Crossing Second Lane of Approach Using a "Rolling Gap."

Statistical Analysis

The Statistical Analysis Software (SAS) computer program was used for the logit transformation analysis. Each approach of roadway 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.

Using the gap acceptance database for each site, the gap length and pedestrian action were considered for each crossing. If the pedestrian rejected the gap the action was assigned a value of zero, while if the pedestrian accepted the gap it was assigned a value of one. A logistic regression was run by using the following program:

proc logistic; model action = gap; run;

By default, SAS *proc logistic* models the probability of y = 0; that is, the program returns the percentage of pedestrians rejecting a gap. Subtracting this value from 1.0 produced the percentage of pedestrians accepting a gap. The predicted values (*p*) for the percentage of pedestrians rejecting a gap are computed by Formula 1:

$$p = \frac{e^{\beta' x}}{1+e^{\beta' x}} * 100 \qquad (1)$$

Similarly, the predicted percentage of pedestrians accepting a gap is computed by Formula 2:

$$q = 1 - p = (1 - \frac{e^{\beta' x}}{1+e^{\beta' x}}) * 100 \qquad (2)$$

For example, the equation for the WB2/EB1 approach of CA-SM-3 is β'x = 6.9634 - 1.1879 * gap. Using Formula 2, the percentage of pedestrians accepting a 7-second gap would be:

$$q = (1 - \frac{e^{6.9634-1.1879(7)}}{1+e^{6.9634-1.1879(7)}}) * 100 = 79.44\%$$

From this equation a graph can be generated showing the cumulative distribution of pedestrians accepting gaps of various lengths. Figure N-6 shows an example of this type of graph.

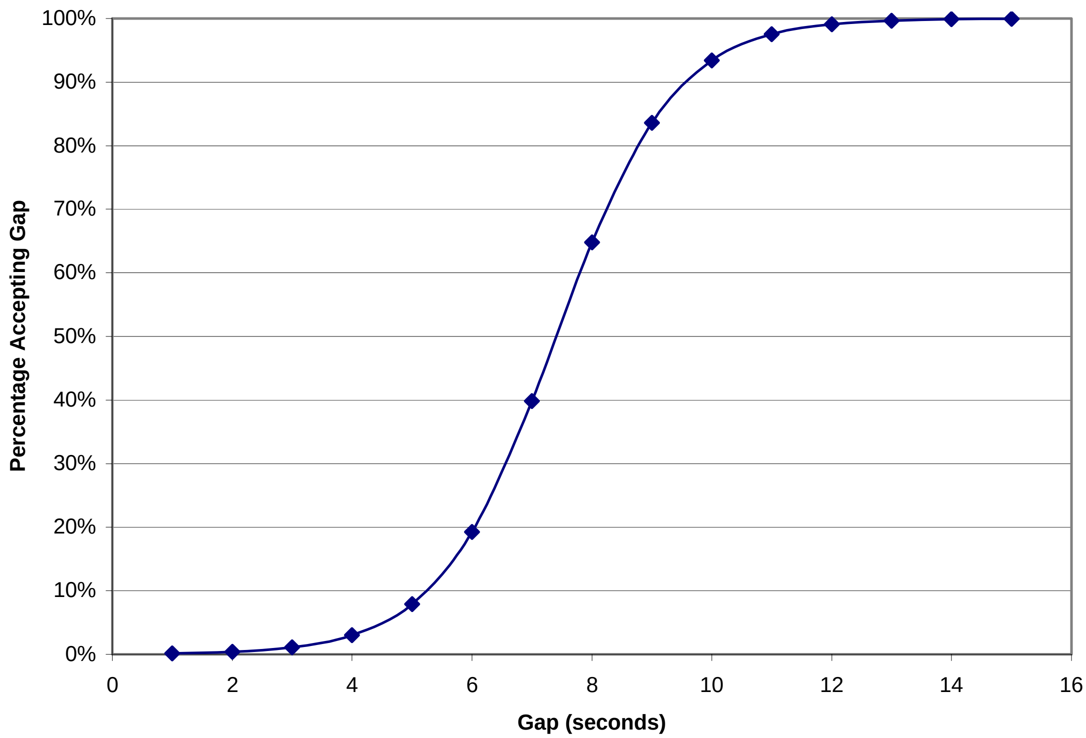


Figure N-6. Sample Cumulative Distribution of Gap Acceptance.

The data from some sites did not meet the convergence criterion. In order for the logistic model to run successfully, the values of accepted and rejected gaps must overlap and not be completely or almost completely separated. That is, there should be a gap length (or small range of gap lengths) that was both accepted and rejected by a considerable number of pedestrians. 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 N-6, 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 the Findings section. The complete set of results from the SAS logistic analysis is shown in Table N-2.

TABLE N-2. Results 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-PG-1	NB 2/SB 1	65.1435-10.6485x	6.2	6.3	21	N
MD-TN-1	NB	6.7212-0.9039x	7.4	9.4	22	Y
MD-TN-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

Using the probability equations obtained from SAS, the accepted gap for each site can be determined. Table N-1 listed the treatment, number of observed pedestrians, number of observed gaps, and crossing width for each approach with greater than 20 crossing pedestrians who made a gap decision. Table N-2 lists the 50th and 85th percentile gap accepted for the 11 approaches with more than 20 pedestrians or pedestrian groups crossing. The approaches had an 85th percentile accepted gap between 5.3 and 9.4 seconds.

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 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 true nature of 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 all but one gap 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. The cumulative distribution for this approach is shown in Figure N-7.

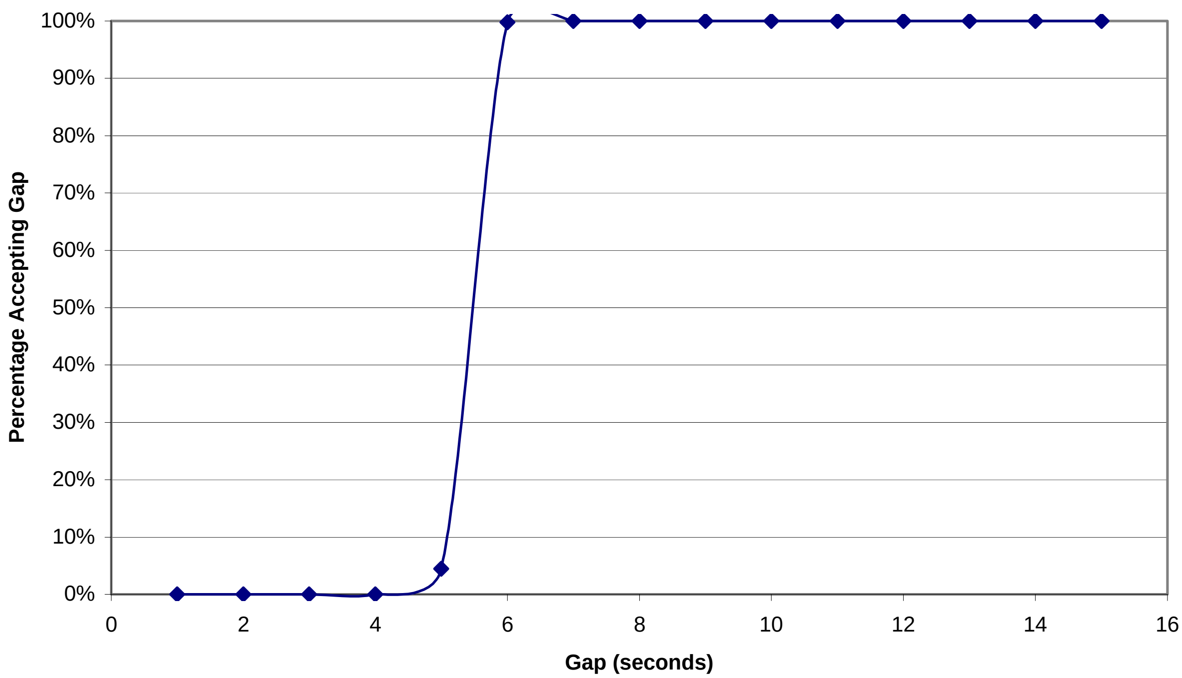


Figure N-7. Cumulative Distribution of Gap Acceptance with Separation of Data.

Table N-3 lists those approaches whose distribution is similar to Figure N-7. 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.

TABLE N-3. 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-PG-1	NB 2/SB 1	6.0	7.0
MD-TN-1	SB	7.0	10.0
WA-KI-3	WB	4.0	6.0

COMPARISON OF OBSERVED AND CRITICAL GAPS

The findings show that the accepted gap increases as crossing distance increases (see Figure N-8). Also shown in Figure N-8 is the plot of the critical gap for a walking speed of 3.5 ft/s (1.1 m/s). Inspection of Figure N-8 reveals that all of the observed 85th percentile accepted gaps were less than the calculated critical gap for a walking speed of 3.5 ft/s (1.1 m/s). Thus, the 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.

Recommendations from Appendix M include the adoption of 3.5 ft/s (1.1 m/s) as the design walking speed. Gap acceptance findings as shown in Figure N-8 indicate that this would be a conservative value to use for crossing distances of at least 30 ft (9.1 m).

Figure N-8 also shows the plots of the critical gap for walking speeds of 3.0 ft/s (0.9 m/s) and 4.0 ft/s (1.2 m/s). Findings from Appendix M recommend 3.0 ft/s (0.9 m/s) for use at intersections with a high number of older pedestrians, and it provides an even more conservative estimate than 3.5 ft/s (1.1 m/s) in comparison to the observed accepted gaps. The plot for a 4.0 ft/s (1.2 m/s) walking speed represents the value that is currently in widespread use; it is just sufficient to serve 85 percent of the observed pedestrians, being approximately equal to the highest observed gap at a crossing distance of 30 ft (9.1 m).

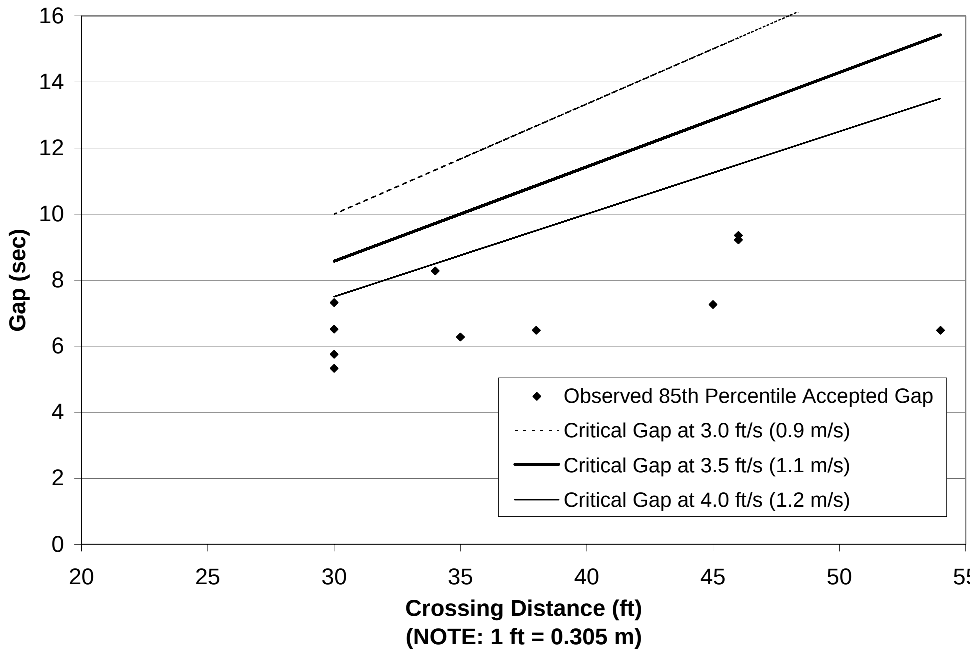


Figure N-8. Comparison of Trends for Observed 85th Percentile Accepted Gaps and Calculated Critical Gaps for Walking Speeds of 3.0, 3.5, and 4.0 ft/s (0.9, 1.05, and 1.2 m/s).

CONCLUSIONS

Taking the above findings into account, the following conclusions can be made from the data:

- A behavioral pattern in response to high volumes of traffic on a multilane approach is the use of a “rolling gap.” Pedestrians often timed their crossing maneuvers to take advantage of an adequate gap in each individual lane, and thus complete their crossings, even though the approach as a whole did not have an adequate gap during their crossings.
- While “rolling gaps” are a behavioral adaptation made by many pedestrians, the design assumption that pedestrians will wait for all lanes to clear produces a more conservative design that minimizes the potential for crashes and injuries for pedestrians who do not accept “rolling gaps.”
- For approaches with more than 20 observed pedestrians, the trend of the 85th percentile accepted gap increases with crossing distance. The critical gap calculations also result in larger gaps for longer crossing distances.
- The observed 85th percentile accepted gaps were less than the calculated critical gaps recommended for design when using a walking speed of either 3.0 ft/s (0.9 m/s) or 3.5 ft/s (1.1 m/s). The latter is recommended for adoption as the design walking speed for general conditions, while the former is recommended for locations with high numbers of older pedestrians.
- The observed 85th percentile accepted gaps were also less than or equal to the calculated critical gaps when using a walking speed of 4.0 ft/s (1.2 m/s), which is commonly used as the current design walking speed.

APPENDIX O

GUIDELINES DEVELOPMENT

In developing the *Guidelines* (see Appendix A), several decisions were made. This Appendix documents the sources of the information and the assumptions or decisions made in selecting the values used in the *Guidelines*. The information presented is organized into a series of questions explored during the development of the *Guidelines*.

WHAT SHOULD THE BASIC FORMAT BE FOR A PEDESTRIAN SIGNAL WARRANT?

The current pedestrian signal warrant uses the number of pedestrians crossing during the peak hour or during any 4 hours along with a check that more than 60 gaps per hour of adequate length are present. Another check is that the proposed location is not within 300 ft (91 m) of an existing traffic control signal. Comparisons of the pedestrian signal warrant with vehicular warrants and discussions with city, county, and state representatives along with participants in two workshops have indicated that a revised pedestrian signal warrant should have the following characteristics:

- Similar features as the vehicular signal warrants, such as a reduction for higher operating speeds and a sliding scale where the minor road requirement decreases as the major road volume increases.
- Sensitive to both pedestrian volume and vehicular volume.
- Sensitive to distance being crossed, with distance being preferred over number of lanes.
- Number of required pedestrians should not exceed the number of required vehicles for a location.
- Preference toward using number of major road vehicles instead of gaps present within the major road flow.

Based upon the above criteria, the research team decided to model the revised pedestrian signal warrant on the format used for the current Signal Warrant 3, Peak Hour, and Warrant 2, Four-Hour Vehicular Volume.

The existing vehicle volume warrants (from which the revised pedestrian warrant was adapted) have higher side-street vehicle volume criteria when the major road is multilane as opposed to 1 lane in each direction. However, review comments indicated that pedestrians had much greater difficulty crossing multilane streets, and the crash rates are typically higher for multilane streets as opposed to one lane in each direction. These comments led the research team to select the "1-lane & 1-lane" vehicle-based curve to be the only curve presented in the revised pedestrian warrant, both for single and multilane major road approaches.

WHAT SHOULD THE CRITERIA BE FOR NUMBER OF PEDESTRIANS FOR CONSIDERATION OF A SIGNAL?

As presented above, the suggestions and recommendations provided to the research team by others and in the research team's engineering judgment, the number of pedestrians should not exceed the number of vehicles used to warrant a traffic signal. Therefore, the pedestrian signal warrant should at least be similar to the vehicle warrants.

The approach requires consideration of the directional distribution of the pedestrians at a crossing since the vehicle volume uses the highest minor road volume while the current pedestrian signal warrant uses total crossing volume.

While it would be reasonable to assume a 50/50 split in crossing distribution for an entire day, a non-equal split would logically be expected during the peak hour.

Pedestrian crossing data were available from two sources: field studies conducted for approximately 4 hours per site for 43 sites, and 11-hour volume counts (both vehicle and pedestrian) at 8 intersections in California. At each intersection, the pedestrian directional split was determined for each hour of available data. For example, if 100 pedestrians crossed the major roadway with 60 crossing in the westbound direction and 40 crossing in the eastbound direction, then the directional split would be 60/40. The cumulative distribution plot for the field studies is shown in Figure O-1 and for the eight California intersections in Figure O-2. These plots only show the data for the higher volume approach (e.g., only the 60 percent would have been included from our previous example). For the 43 field study sites, about half of the hours had a 67/33 percent distribution. For the eight California sites, about half of the hours had a 72/28 percent distribution between directions. When only the peak hour is considered for the California data, the following distributions were observed:

- 62/38,
- 70/30,
- 75/25,
- 86/14,
- 86/14,
- 91/9,
- 100/0, and
- 100/0.

Therefore, 6 of the 8 hours had at least a distribution of 75/25.

Based on the findings from the 43 field study sites and the eight California sites along with engineering judgment, the research team selected the 75/25 split as being representative of a typical pedestrian distribution during a peak hour. For the 4-hour warrant, the distribution is also suggested to be a 75/25 split.

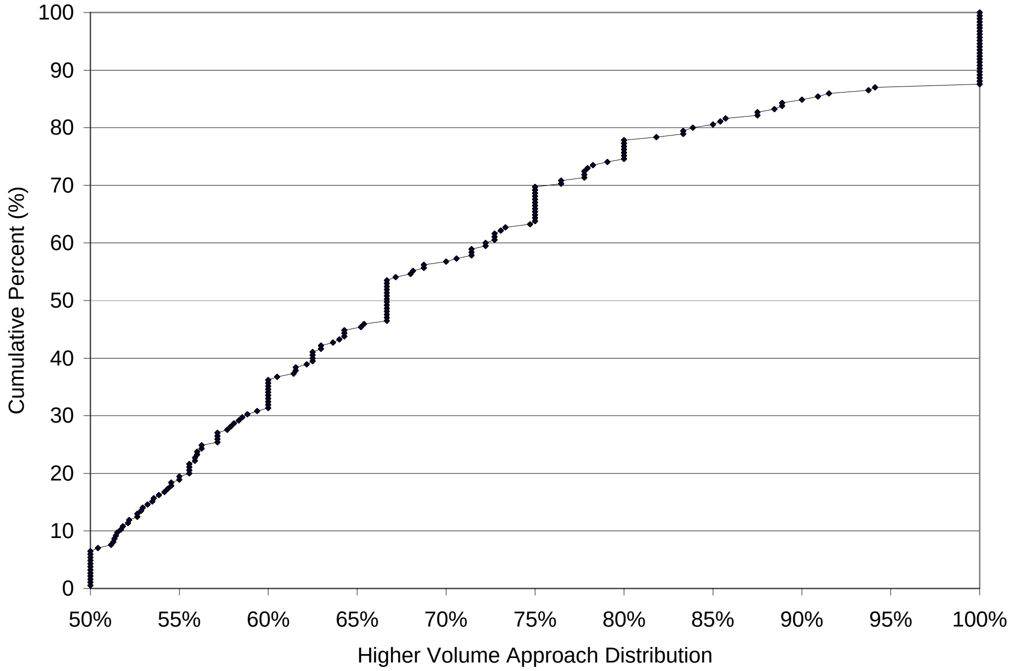


Figure O-1. Cumulative Plot of Pedestrian Directional Split for 43 Study Sites (Represents 185 Hours of Data).

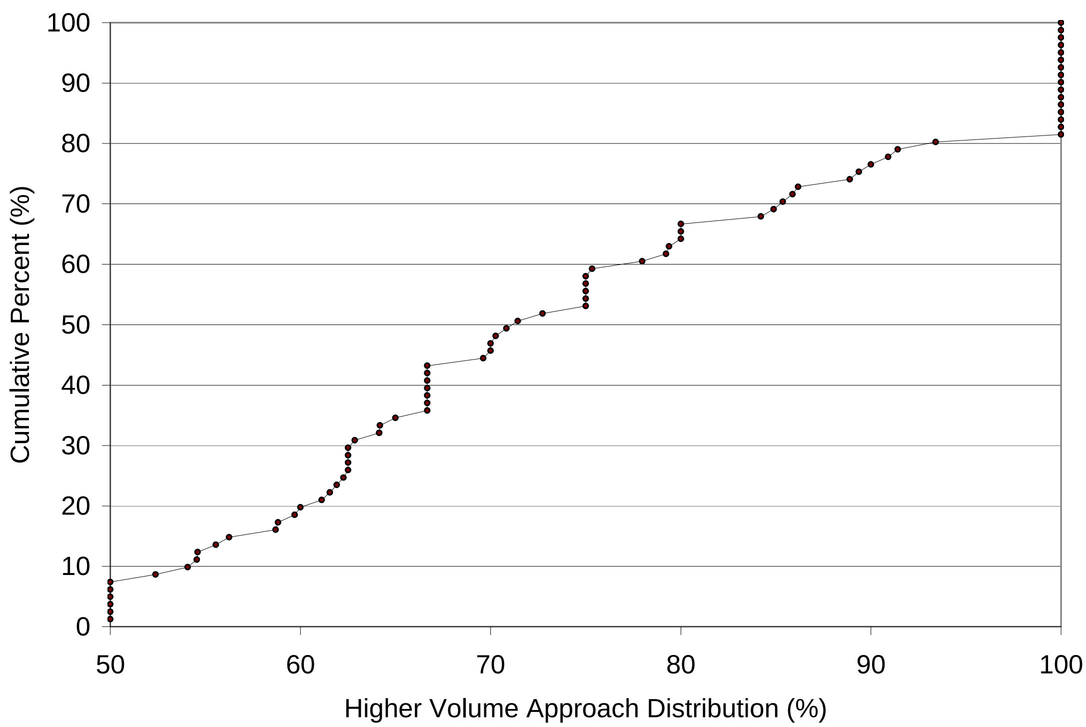


Figure O-2. Cumulative Plot of Pedestrian Directional Split for Eight California Sites (Represents 88 Hours of Data).

With a 75/25 directional distribution split, 190 pedestrians per hour would translate to 143 pedestrians per hour on the highest approach during the peak hour. When the 70 percent reduction factor is used, the value then goes to 100 pedestrians per hour on the highest approach.

The philosophy of equating the pedestrian signal warrant to a vehicle signal warrant results in both an increase in the minimum number of pedestrians (at lower major road volumes) and a decrease in the minimum number of pedestrians (at higher major road volumes). The suggested change in the pedestrian signal warrant peak-hour pedestrian volume is shown in Figure O-3. At peak-hour major road volumes of 1200, the pedestrian volume criteria will **increase** from the current warrant (however, the research team is proposing that other pedestrian treatments be considered). Above 1200 the pedestrian volume criteria will **decrease** from the current warrant. The minimum pedestrian criteria will match the minimum vehicle requirement of 100 veh/h on the highest volume minor-road approach when the major road volume is greater than 1700 veh/h.

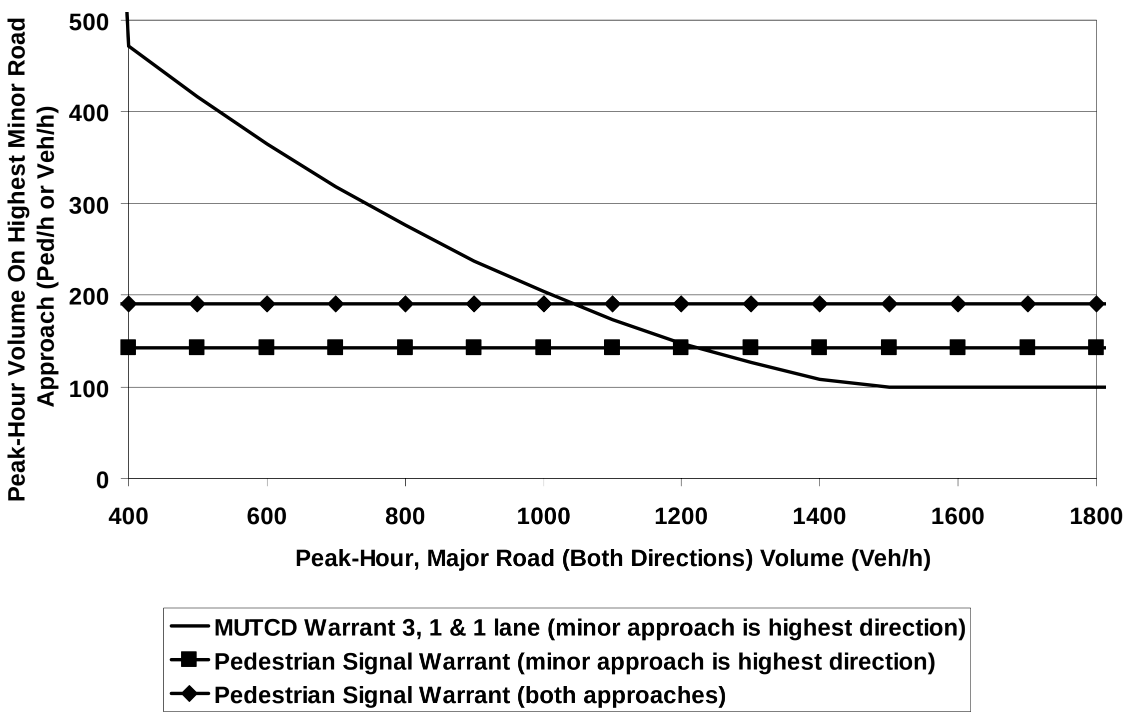


Figure O-3. Comparison between Warrant 3 (Peak Hour) and Warrant 4 (Pedestrian, Adjusted to Highest Approach Volume).

To simplify the *Guidelines,* equations are used in place of the *MUTCD* curves. The regression equations developed by Sack and Lawson (*133*) for all MUTCD curves are shown in Table O-1. These equations can determine the minimum number of vehicles (or pedestrians) that would be needed at the given major road volume to meet the signal warrant.

TABLE O-1. Equations for the Signal Warrant Curves (*133*).

Equation	R^2	Range	Lanes
Four-Hour Warrant (#2)			
$Y = 557.978 - 0.73003\,X + 0.00027\,X^2$	0.999885	400-1160	1-1
$Y = 643.445 - 0.73144\,X + 0.00023\,X^2$	0.999908	400-1350	2-1
$Y = 858.973 - 0.97877\,X + 0.00031\,X^2$	0.999940	470-1320	2-2
Minimum Y for minor street with 2 lanes is 115 veh/h			
Minimum Y for minor street with 1 lane is 80 veh/h			
Four-Hour Warrant (#2-with 70% factor)			
$Y = 396.803 - 0.76930\,X + 0.00044\,X^2$	0.999900	270-800	1-1
$Y = 457.134 - 0.76954\,X + 0.00037\,X^2$	0.999887	280-940	2-1
$Y = 614.734 - 1.03083\,X + 0.00049\,X^2$	0.999957	330-900	2-2
Minimum Y for minor street with 2 lanes is 80 veh/h			
Minimum Y for minor street with 1 lane is 60 veh/h			
Peak-Hour Warrant (#3)			
$Y = 734.125 - 0.74072\,X + 0.00021\,X^2$	0.999909	450-1450	1-1
$Y = 809.779 - 0.67328\,X + 0.00015\,X^2$	0.999879	510-1740	2-1
$Y = 1081.658 - 0.93419\,X + 0.00023\,X^2$	0.999913	610-1650	2-2
Minimum Y for minor street with 2 lanes is 150 veh/h			
Minimum Y for minor street with 1 lane is 100 veh/h			
Peak-Hour Warrant (#3-with 70% factor)			
$Y = 529.197 - 0.80083\,X + 0.00035\,X^2$	0.999693	320-1010	1-1
$Y = 586.099 - 0.73111\,X + 0.00025\,X^2$	0.999943	360-1200	2-1
$Y = 762.050 - 0.95887\,X + 0.00033\,X^2$	0.999920	420-1170	2-2
Minimum Y for minor street with 2 lanes is 100 veh/h			
Minimum Y for minor street with 1 lane is 75 veh/h			
Y is minor street (high volume approach, in vehicles per hour)			
X is major street (total of both approaches, in vehicles per hour)			

AT WHAT POSTED SPEED OR 85TH PERCENTILE SPEED VALUE SHOULD THE USER BE DIRECTED TO A SET OF REDUCED VALUES?

The *MUTCD* states that "if the posted or statutory speed limit or the 85th percentile speed on the major street exceeds 40 mph (70 km/h) or if the intersection lies within the build-up area of an isolated community having a population of less than 10,000" reduced warrants may be used. This reduction is commonly known as a "70% factor." The research team recommends that the revised pedestrian signal warrant include similar reduced criteria for higher speed roadways. The recommendation is that a reduction factor be applied for roads with speeds of 35 mph (56 km/h) or greater. Reasons for providing a reduction factor include drastically decreased survival rate (55 percent at 30 mph [48 km/h], 15 percent at 40 mph [64 km/h]) and the lower recorded compliance at higher speed limits. The value of 40 mph (64 km/h) also corresponds to the point at which marked crosswalks alone are not recommended at unsignalized intersections (*31*).

COUNT HIGHEST OR BOTH APPROACHES?

Practitioners have noted that current counting boards favor counting all pedestrians rather than just one approach. To "match" the current vehicle warrants, however, the count on only the highest approach is needed. The availability of directional distribution splits can be used to convert total pedestrian crossings to a value that would be representative of the highest approach value. Of course, only the highest approach could be counted instead of using a conversion factor. Either method (highest approach or all pedestrians crossing major roadway) could be used and each has advantages and disadvantages. Members of the National Committee expressed the preference to having a procedure that counts all pedestrians crossing the major roadway, as it is easier in presentations with citizens. To accommodate this preference and match the values present in the current vehicle warrant, values would need to be converted from the highest approach value used in the vehicle warrant to total of both approaches. This was done using the 75/25 directional distribution.

WHAT SHOULD BE THE MINIMUM PEDESTRIAN VOLUME?

The 2001 FHWA study (*31*) on safety effects of marked versus unmarked crosswalks at uncontrolled locations recommended "a minimum of 20 pedestrian crossings per vehicular peak hour (or 15 or more pedestrians in special population groups, e.g., elderly and/or child pedestrians) exist at a location before considering the installation of a marked crosswalk." The 20 ped/h value was selected for the *Guidelines*. When the 70 percent reduction factor is used, the value then goes to 14 pedestrians.

WHAT SHOULD BE THE ASSUMED WALKING SPEED FOR THE *GUIDELINES?*

Users can select a walking speed for use in the *Guidelines*. Based on previous research and the data collected at the 43 sites in this study, the suggested walking speeds are:

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

These walking speeds reflect 15th percentile speeds. The current pedestrian signal warrant contains the option to reduce the pedestrian volume crossing the major roadway by as much as 50 percent if the average crossing speed is less than 4 ft/s (1.2 m/s). This should be revised to reflect the new suggested walking speed (e.g., if the 15th percentile crossing speed is less than 3.5 ft/s [1.1 m/s]).

HOW SHOULD CROSSING DISTANCE BE CONSIDERED?

The distance to be crossed influences a pedestrian decision on accepting or rejecting gaps. This distance could be measured as a function of the number of lanes; however, that could eliminate consideration of parking or bike lanes along with the median treatment (e.g., how to factor in a left-turn bay when a 6-ft [2 m] raised median is present)? Using the distance to be crossed rather than the number of lanes will directly consider the entire distance. It will also allow easy consideration of the presence of a median refuge island – the crossing distance will represent the distance from one curb to the next curb.

SHOULD PEDESTRIAN DELAY BE CONSIDERED, AND IF SO, HOW?

For vehicle traffic signal warrants, the critical criteria are volumes and major road speed. In addition to those criteria, pedestrian delay is proposed to be the determining factor for selecting pedestrian crossing treatments in the *Guidelines*. If the estimated pedestrian delay is low, then less restrictive crossing treatments are recommended (such as basic marked crosswalks or enhanced/active devices). If pedestrian delay is high, then more restrictive crossing treatments are recommended to reduce pedestrian delay to a tolerable level.

The *MUTCD* Warrant 3, Peak Hour, is intended for use at a location where minor-street traffic “suffers undue delay when entering or crossing the major street.” One of the criteria considered within Warrant 3 is total stopped time delay experienced by the traffic on a minor-street approach. For a one-lane approach the criterion is 4 vehicle-hours on one minor street approach. The 4-hour value was used with the pedestrian delay equation and compared to the plot of the peak-hour criteria for vehicles (and being considered for pedestrians) as shown in the 2003 *MUTCD* Figure 4C-3. The comparison of the plots revealed that the criteria would greatly change if 4-hour pedestrian delay criteria were used to warrant a signal. Other considerations such as driver yielding behavior (an acceptable gap is created by a yielding motorist when that gap may not be present previously) and multiple pedestrians crossing in the same gap created hesitations with the acceptance of a 4 pedestrian-hour criterion. On the other hand are the considerations that pedestrians require more time than a vehicle to clear an intersection and not all vehicles yield to pedestrians. Therefore, the research team decided to use delay to separate the different levels in the *Guidelines* and to use the current vehicle warrant as the basis for the proposed pedestrian signal warrant.

The G*uidelines* assume that the critical threshold for pedestrian delay is 1, 4, or 16 pedestrian-hours in the peak hour **on the highest approach**. These delay values must be adjusted to reflect counting all pedestrians crossing the intersection rather than just those on the higher volume approach. Using the 75/25 directional distribution split, the pedestrian delay values of interest then become 1.3, 5.3, and 21.3 pedestrian-hours in the peak hour.

HOW DOES COMPLIANCE FIT WITH THE *GUIDELINES*?

Compliance is implicitly considered in the *Guidelines* by assuming that different categories of crossing treatments have different levels of compliance. The data analysis indicated that certain categories of devices generally produced higher compliance levels. However, the analysis also indicated that the ranges for compliance in several categories were quite large. Thus, the *Guidelines* group Enhanced and Active devices into the same category and instead make a delineation for “expected” compliance based on area type (pedestrian friendliness of the area in which the device will be installed). The higher expected compliance for the more restrictive devices (in the Active and Red categories) will ultimately lower the pedestrian delay, thereby yielding comparable pedestrian delay for all devices.

WILL “TOO MANY SIGNALS” RESULT FROM THE PROPOSED *GUIDELINES*?

The proposed *Guidelines for Pedestrian Treatments* were used with two data sets to determine the impacts from implementing the *Guidelines* on number of signals and number of red treatments.

Sources of Data

The data sets included in the evaluations were:

- **Field Study Sites.** Field data collected at 42 intersections located in Maryland, Texas, Utah, Washington, Oregon, California, and Arizona. Generally 4 hours of data on pedestrian and motorist behavior were collected, so the peak pedestrian hour may not have been identified. The data from these locations were used to determine walking speed, compliance rates, and to investigate other performance measures as part of this TCRP/NCHRP project.
- **Santa Ana.** Estimates of pedestrian and traffic volume at 156 unsignalized marked crosswalks in Santa Ana, California. The data set represents 100 percent of the marked uncontrolled crosswalks in the city in 1997. The volume data available for evaluation were average daily traffic for vehicles and 24-hour pedestrian counts. These values originally used a 2-hour count and assumed conversion factors. The person who collected the data recommended the following factors to convert the 24-hour pedestrian count to peak-hour pedestrian count:
    - For white crosswalks: 10 percent and
    - For yellow crosswalks (i.e., near a school): 25 percent.
- A 10 percent factor was used to convert the vehicle ADT to a peak-hour value.

Findings

Field Study Sites

The *Guidelines* were used to evaluate the 42 field study sites. The recommended treatment category from the *Guidelines* procedure was compared to the treatment currently in place. This evaluation may underestimate the type of device since the available 4 hours of pedestrian and vehicle data may not reflect the peak period of the day. For the data available, a full signal was warranted at only one of the 42 sites. This site currently has a midblock traffic signal.

For each site, the category (crosswalk, active/enhanced, red, or signal) recommended by the *Guidelines* procedure was compared to the category represented by the existing device. For example, if a half-signal was present at the existing site, then the existing category was “red.” The proposed category was compared to the existing category. If the proposed category was the same as the existing category, then the site was called “same.” If the recommended category represented a higher level of traffic control than present at the existing site, then the site was called “more restrictive” (e.g., if an active/enhanced treatment was present and the proposed *Guidelines* recommended a red device). If the difference was more than two levels, then the site was “much more restrictive.” If the device recommended represented a lower level of control, then the site was called “less restrictive” (for a one-level difference) or “much less restrictive” (for a two-level difference). For the 42 field study sites, Table O-2 lists the comparison of the *Guidelines* results with the current treatment.

TABLE O-2. Comparison of Guidelines to Existing Treatments.

Comparison	Number of Sites	Percentage
Same	20	48
More Restrictive	11	26
Less Restrictive	8	19
Much Less Restrictive	1	2
Much More Restrictive	2	5
TOTAL	42	100

For about half of the sites, the recommended category based on the *Guidelines* matched the existing treatment. Only 7 percent of the sites (three sites) showed a large difference between the installed treatment and the proposed *Guidelines*. In summary, the *Guidelines* appear to adequately reflect the levels of treatment being installed. Thus, we expect that public agencies using these *Guidelines* would not be introducing significantly more or less restrictive traffic control devices than installed at our 42 field study sites.

Santa Ana, California

For the Santa Ana data, the findings were divided into those crossings with white markings and those crossings with yellow markings. Crossings near schools in California are marked using yellow rather than white. Crossing guards are typically placed at these crossings, and that can influence the decision on whether a traffic signal is needed. Because of the intense peaking occurring during school hours and the presence of a crossing guard, engineering judgment may indicate that even when volumes are higher than the values in the warrants a signal is not needed.

Of the 156 crossings, 86 were yellow and 70 were white. A review of just the number of pedestrians in the peak hour shows that 15 crossings (13 yellow and 2 white crossings) have sufficient pedestrians (more than 190 pedestrian in an hour) to consider a signal using the current warrant. Because the gap characteristics were not available, the vehicle volumes were reviewed to provide an idea of which crossings may have sufficient vehicle volume to consider a signal. About 6 of the 15 crossings had sufficient vehicle volumes where additional investigation may be of value. The remaining nine crossings had low vehicle volumes and would probably not meet the signal warrant criteria. Of the six that should have additional investigation, we believe that only two of the crossings would probably meet the signal warrant criteria. So with existing criteria, two to six of the 156 crossings could warrant a signal.

The use of the proposed Signal Warrant recommendations requires that the speed on the major roadway be known. Because this information is not available, two reviews were conducted, one where we assumed that all sites were on roads with 35 mph (56 km/h) or less and one where all the roads were assumed to be 40 mph (64 km/h) or more. These crossings probably reflect a mix of speeds, so the 35 mph (56 km/h) should represent the minimum number of signals and the 40 mph (64 km/h) assumption the maximum number of signals. Table O-3 lists the results of the analysis.

TABLE O-3. Number of Crossings Where Signals Are To Be Considered.

Color of Pavement Markings	Existing Pedestrian Signal Warrant, number exceeding 190 ped/h (estimated number that would probably meet other requirements)	Proposed Pedestrian Signal Warrant for Roads with 35 mph (55 km/h) or less speed	Proposed Pedestrian Signal Warrant for Roads with 40 mph (64 km/h) or more speed
Yellow	13 (5)	10	14
White	2 (1)	2	4
TOTAL	15 (6)	12	18

Because of the characteristics of the yellow crossings (intense peaking, crossing guard present, etc.), the following discussion only refers to white-marked crossings. The proposed signal warrant would result in two to four signals out of the 70 crossings, with one to two of them being warranted when they would not have been warranted under the existing criteria. This represents an increase of 1 to 3 percent in the number of signals within the system. It was estimated that the city had about 300 signals at the time of the study.

The *Guidelines* also provide advice on when to consider other types of devices including "red devices." Table O-4 lists the number of crossings where a red device would be considered. Approximately 1 to 9 percent of the crossings (depending upon the speed and compliance levels actually present) would warrant a red device.

TABLE O-4. Number of Crossings Where a Red Device Is To Be Considered.

Color of Pavement Markings	Proposed Guidelines for Roads with 35 mph (55 km/h) or less speed and low compliance	Proposed Guidelines for Roads with 35 mph (55 km/h) or less speed and high compliance	Proposed Guidelines for Roads with 40 mph (64 km/h) or more speed and low compliance	Proposed Guidelines for Roads with 40 mph (64 km/h) or more speed and high compliance
Yellow	8 (9%)	4 (5%)	9 (10%)	8 (9%)
White	6 (9%)	4 (6%)	5 (7%)	5 (7%)
TOTAL	14 (9%)	8 (5%)	14 (9%)	13 (8%)

Comments

Two data sets were used to evaluate the potential impact of the proposed *Guidelines*. The evaluation compared the recommendations from the *Guidelines* to the existing type of treatments to determine how closely the *Guidelines* match current engineering judgment in selecting treatments.

For the data set that includes 42 sites located in seven states, the recommendations for about half of the sites were the same as the existing treatment and 93 percent of the sites were within one category level (as an example, the *Guidelines* recommended an active/enhanced device when a marked crosswalk was the treatment present). Therefore, we expect that public agencies using these *Guidelines* would not be introducing significantly more or less restrictive traffic control devices than installed at our 42 field study sites.

For the 70 white marked crosswalk sites in Santa Ana, one to two of the sites probably already meet the current *MUTCD* signal warrant. Using the proposed revised signal warrant and assuming that the speed on the major roadway is 35 mph (55 km/h) or less, two of the sites would meet the warrant for a signal. If the speed on the major roadways is 40 mph (64 km/h) or more (speeds are not known), then four sites would meet the warrant for a signal. The proposed signal warrant would increase the number of signals by about two to three. An estimate of the number of signals for the community was 300; therefore, the changes result in an increase of less than 1 percent. The *Guidelines* do include recommendations for red devices, and based upon the data available and making reasonable assumptions, red devices are suggested for approximately 7 percent of the marked crosswalks.

In summary, the draft *Guidelines* appear to adequately reflect the levels of treatment being installed and will not result in major changes in treatment device selection for those communities that actively consider pedestrians.

WHAT CHANGES WOULD PRACTITIONERS MAKE TO THE DRAFT *GUIDELINES?*

As part of the development of the *Guidelines* the research team sent the draft *Guidelines* to six agencies for beta testing. The set of practitioners included a state department of transportation representative and a community not involved in the pedestrian data collection portion of the study. A two-page survey form was distributed with the draft *Guidelines* to focus the review and provide feedback in specific areas.

Findings from Survey

Eleven questions were asked within the survey. For each of these questions, the responders were to provide a numerical response on the scale of 1 (the best) to 5 (needs lots of work). They also had the opportunity to expand upon their rating. Table O-5 lists the questions along with the average response. One reviewer’s scores for Questions 5 and 9 was heavily influenced by the size of the pedestrian delay value from one of the test locations. The reviewer felt the delay value was not realistic and questioned the validity of the *Highway Capacity Manual* equation.

TABLE O-5. Responses from Survey Questions.

1. Overall impression of the document. Average = 2.25
2. Did you understand Step 1 directions? Average = 1.40
3. Did you understand Step 2 directions? Average = 1.60
4. Did you understand Step 3 directions? Average = 3.00
   The reviewers provided some suggested changes to improve the readability of this step.
5. Did you understand Step 4 directions? Average = 3.00
6. Did you understand Step 5 directions? Average = 1.60
7. Were the technical needs easy to understand? Average = 2.40
8. Did you find the document to be user friendly? Average = 2.80
9. Were the findings appropriate for your study location(s) without a pedestrian refuge island? Average = 3.20
10. Were the findings appropriate for your study location with a pedestrian refuge island? Average = 2.75
11. Were the findings appropriate for your study location with high speeds? Average = 2.80

Scale: 1 (the best) to 5 (needs lots of work)
Averages are based upon five responses.

The survey also included six discussion questions. Following is a synopsis of the responses.

1. A previous reviewer suggested that we include monographs for common combinations of walking speed and crosswalk distances; therefore, a sample of graphs was generated and included in the Appendix: Samples of Guidelines. Are there other combinations of walking speed and crosswalk distance that should be included?

About half said the material provided was fine. The following are suggested dimensions for additions:

- Four-lane (divided and undivided) cross section (to be able to compare to the scenario when a pedestrian refuge island is added)
  - 66 ft (20 m) (for four lanes @ 12 ft [3.7 m] + 18 ft [5.5 m] median)
  - 36 ft (11 m) (for two lanes @ 12 ft [3.7 m] + one turn lane @ 12 ft [3.7 m])
- Six-lane (divided and undivided) cross section (to be able to compare to the scenario when a pedestrian refuge island is added)
  - 100 ft (31 m) (for seven lanes @ 12 ft [3.7 m] + 16 ft [5 m] for two parking or bike lanes)
  - 44 ft (13 m) (for three lanes @ 12 ft [3.7 m] + one parking lane of 8 ft [2.4 m])
- 56 ft (17 m)

2. Are there other pedestrian crossing treatments that should be included in the Appendix: Description of Sample Treatments?

No additional treatments were suggested; however, the reviewers did suggest the following:

- Photos should be updated to current (2003) *MUTCD* standards for signs and colors of flags. [Because of the time and costs to accomplish this suggestion, the research team is noting in the guidelines when a sign is not in the current manual.]
- Add a note that the HAWK is being requested for "permission for experimentation" to FHWA. [Comment added.]

One of the reviewers was concerned with the inclusion of the red devices since the treatments can not be used if not in the *MUTCD*. While supporting the concept of "red devices," the reviewer is frustrated with them not being in the *MUTCD*. [The research team added comments regarding the need to request permission for experimentation on those devices not in the *MUTCD*.]

3. The Guidelines were developed for the peak hour. Would you also want or use 4-hour criteria (similar format as provided in the MUTCD for Warrant 2) if such were available? It appears that the 4-hour vehicle warrant is about 65 percent of the peak-hour vehicle warrant and we envision that the pedestrian warrants would have a similar relationship.

Four of the five reviewers supported the idea of having a 4-hour warrant; therefore, that material is being added to the suggested changes for the *MUTCD* signal warrant.

4*. Based on your evaluation results and intuition, are the criteria dividing the classes of treatments (1, 4, and 16 pedestrian-hours) appropriate?*

Most of the reviewers supported the criteria. One wanted more information on why the particular numbers were selected (e.g., why 16 rather than 15?). The one who didn't support the criteria wrote "don't understand question."

5. Were you satisfied with the results from your study locations? Why or why not?

Two were satisfied and two were not due to "ridiculous estimate of pedestrian delay."

6. Will you implement the recommendations from your study locations? Why or why not?

In some situations the agency plans to implement the recommended treatment, while in others the reviewer was not convinced because of the high pedestrian delay value calculated (higher than what they believe is present) or that the "red" treatments are not in the *MUTCD*.

Other comments or observations included the following:

- "I like the concept of having relative and increasing levels of pedestrian treatments depending upon what the conditions are."
- "I like the sequential thought process as outlined in the report and the flowchart."
- One reviewer stated "not sure if 300 ft (91 m) the best cut-off for distance to nearest signal" and another indicated that the dimension should be a function of the speed on the roadway. [No changes were made since the 300 ft (91 m) is based upon the value currently included in the *MUTCD*.]
- Two reviewers felt that the actual pedestrian delay could be used rather than a calculated delay. [We added a comment in the Worksheet indicating that actual pedestrian delay can replace the calculated delay if available.]

Reviewers suggested the following changes to the *Guidelines*: (1) revise the pedestrian flags discussion to indicate that they should have a distinct shape and color and (2) provide additional information regarding alternate flashing patterns for the overhead flashing installations. [A generic statement about flashing patterns was added to the *Guidelines*. Making recommendations on changes to the pedestrian flag is beyond the scope of this study so no changes were made.]

SUMMARY

In this project, the research team developed *Guidelines* that describe different engineering treatments that can improve unsignalized pedestrian crossings. The *Guidelines* include quantitative criteria that can be used to determine an appropriate type of crossing treatment, from marked crosswalks to warning devices to red signal/beacon devices to full traffic signals. The main criteria for determining an appropriate treatment type includes vehicle traffic volumes, projected or actual pedestrian volumes, width of street being crossed, and walking speed. For traffic control devices other than traffic signals, the determination of an appropriate crossing treatment type is based on acceptable levels of pedestrian delay as well as motorist compliance. The *Guidelines* include a revised pedestrian warrant for traffic signals, which is currently being considered for adoption in the *MUTCD*. In formulating a revised signal warrant, many engineers expressed concern about a revised signal warrant permitting too many additional signals. A sensitivity analysis by the research team indicated that using the revised signal warrant in a test city would result in only a minimal increase (additional 1 to 3 percent, depending upon assumptions) in the number of traffic signals within their jurisdiction. Further, a comparison of recommendations from the *Guidelines* to crossing treatments actually provided at the study sites indicated that the recommendations in the *Guidelines* were in relatively close agreement to current engineering judgment about providing crossing treatments.

REFERENCES

1. *Manual on Uniform Traffic Control Devices for Streets and Highways.* Federal Highway Administration. 2003. http://mutcd.fhwa.dot.gov/kno-2003.htm. Accessed January 2004.
2. Voss, J.O., and L. Parks, *Operational and Safety Issues of British Columbia's Unique Pedestrian Signals*, British Columbia Ministry of Transport, Vancouver, British Columbia, July 17, 2001.
3. Nassi, R. B., "Pedestrians," Chapter 13 in *Traffic Control Devices Handbook*. Pub. No. IR-112, Institute of Transportation Engineers, Washington, D.C. 2001.
4. Glock, J.W., R.B. Nassi, R.E. Hunt, and B.W. Fairfax, *Implementation of a Program to Reduce Pedestrian Related Accidents and Facilitate Pedestrian Crossings*, City of Tucson Transportation Department, Tucson, Arizona, 2000.
5. Zegeer, C., K. Opiela, and M. Cynecki, *Pedestrian Signalization Alternatives*, Federal Highway Administration, Washington, D.C., July 1985.
6. Watkins, K.F., *Cambridge's Traffic Calming Program: Pedestrians are the Focus*, Institute of Transportation Engineers, Washington, DC, unknown date.
7. Hughes, R., H. Huang, C. Zegeer, and M. Cynecki, *Evaluation of Automated Pedestrian Detection at Signalized Intersections*, Report No. FHWA-RD-00-097, Federal Highway Administration, Washington, D.C., August 2001.
8. Beckwith, D.M., and K.M. Hunter-Zaworski, "Passive Pedestrian Detection at Unsignalized Crossings," In *Transportation Research Record 1636*, Transportation Research Board, National Research Council, Washington, D.C., 1998, pp. 96-103.
9. Allsbrook, L.E., "Pedestrian Signal Countdown Device." *Pro Bike News*. May-June 1999. Bicycle Federation of America, Washington, D.C.
10. Leonard, J., and M. Juckes. *Behavioural Evaluation of Pedestrians and Motorists towards Pedestrian Countdown Signals.* Dessau-Soprin Inc. O/Ref: 4723-100. Montreal, Quebec, March 1999.
11. Farraher, B.A., "Pedestrian Countdown Indication – Market Research and Evaluation." *ITE Compendium of Papers.* Nashville, TN. 2000.
12. Huang, H., and C. Zegeer. *The Effects of Pedestrian Countdown Signals in Lake Buena Vista*. Highway Safety Research Center, University of North Carolina, Chapel Hill, North Carolina, November 2000.
13. Botha, J.L., A.A. Zabyshny, J.E. Day, R.L. Northouse, J.O. Rodriquez, and T.L. Nix. *Pedestrian Countdown Signals: An Experimental Evaluation*. Final Report to the California Traffic Control Devices Committee. San Jose, California, May 2002.
14. Center for Urban Transportation Research, *Making Crosswalks Safer for Pedestrians: Application of a Multidisciplinary Approach to Improve Pedestrian Safety at Crosswalks in St. Petersburg, Florida,* University of South Florida, Tampa, Florida, July 2000.
15. Fisher, J.E., *The Smart and Smarter Pedestrian Warning*, City of Los Angeles Department of Transportation, Los Angeles, California, no date.
16. Van Winkle, J.W., and D.A. Neal, *Pedestrian-Actuated Crosswalk Flashers*, Paper presented at the ITE 2000 Annual Meeting, Institute of Transportation Engineers, Nashville, TN. August 2000.

17. Sparks, J.W., and M.J. Cynecki, "Pedestrian Warning Flashers in an Urban Environment: Do They Help?" In *ITE Journal*, Vol. 60, No. 1, Institute of Transportation Engineers, January 1990, pp. 32-36.
18. Whitlock & Weinburger Transportation, Inc., *An Evaluation of a Crosswalk Warning System Utilizing In-Pavement Flashing Lights*, Santa Rosa, California, April 10, 1998.
19. Godfrey, D., and T. Mazzella, *Kirkland's Experience with In-Pavement Flashing Lights at Crosswalks*, Presented at the ITE/IMSA Annual Meeting, Lynnwood, Washington, February 8, 1999, accessed at http://www.ci.kirkland.wa.us/depart/pw/transportation/flscrswk.htm.
20. Boyce, P., and J. Van Derlofske, *Pedestrian Crosswalk Safety: Evaluating In-Pavement, Flashing Warning Lights*, Report FHWA-NJ-2002-15, Rensselaer Polytechnic Institute, Troy, New York, March 2002.
21. *City of Fountain Valley Illuminated Crosswalks: An Evaluation Study and Policy Recommendations*, Katz, Okitsu & Associates, October 2000, accessed at http://www.katzokitsu.com/peds.htm.
22. Huang, H., R. Hughes, C. Zegeer, and M. Nitzburg, *An Evaluation of the LightGuard™ Pedestrian Crosswalk Warning System*, Highway Safety Research Center, University of North Carolina, Chapel Hill, North Carolina, June 1999.
23. Huang, H., *An Evaluation of Flashing Crosswalks in Gainesville and Lakeland*, Highway Safety Research Center, University of North Carolina, Chapel Hill, North Carolina, November 2000.
24. Prevedouros, P.D., *Evaluation of In-Pavement Flashing Lights on a Six-Lane Arterial Pedestrian Crossing*, Paper presented at the ITE 2001 Annual Meeting, Institute of Transportation Engineers, Washington, D.C., August 2001.
25. Nitzburg, M., and R.L. Knoblauch, *An Evaluation of High-Visibility Crosswalk Treatments—Clearwater, Florida*, Report No. FHWA-RD-00-105, Federal Highway Administration, Washington, D.C., August 2001.
26. Huang, H., C. Zegeer, and R. Nassi, "Effects of Innovative Pedestrian Signs at Unsignalized Locations: Three Treatments," In *Transportation Research Record 1705*, Transportation Research Board, National Research Council, Washington, D.C., 2000, pp. 43-52.
27. Van Houten, R., "The Effects of Advance Stop Lines and Sign Prompts on Pedestrian Safety in a Crosswalk on a Multilane Highway," In *Journal of Applied Behavioral Analysis*, Volume 21, pp. 245-251, 1988.
28. Van Houten, R., and L. Malenfant, "The Influence of Signs Prompting Motorists to Yield before Marked Crosswalks on Motor Vehicle-Pedestrian Conflicts at Crosswalks with Flashing Amber," In *Accident Analysis & Prevention*, Vol. 24, No. 3, 1992, pp. 217-225.
29. Van Houten, R., J.E.L. Malenfant, and D. McCusker, "Advance Yield Markings: Reducing Motor Vehicle-Pedestrian Conflicts at Multilane Crosswalks with Uncontrolled Approach," In *Transportation Research Record 1773*, Transportation Research Board, National Research Council, Washington, D.C., 2001, pp. 69-74.
30. Van Houten, R., J.E.L. Malenfant, and P. Hochstein, *Animated LED "Eyes" Traffic Signals: Executive Summary*, Submitted to National Academy of Sciences, Intelligent Transportation Systems, Washington, D.C., December 1999.

31. Zegeer, C.V., J.R. Stewart, and H. Huang, *Safety Effects of Marked vs. Unmarked Crosswalks at Uncontrolled Locations: Executive Summary and Recommended Guidelines*, Report No. FHWA-RD-01-075, Federal Highway Administration, Washington, D.C., March 2002.
32. Zegeer, C.V., J.R. Stewart, H. Huang, and P. Lagerway, "Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Analysis of Pedestrian Crashes in 30 Cities," In *Transportation Research Record 1773*, Transportation Research Board, National Research Council, Washington, D.C., 2001, pp. 56-68.
33. Koepsell, T., L. McCloskey, M. Wolf, A.V. Moudon, D. Buchner, J. Kraus, and M. Patterson, "Crosswalk Markings and the Risk of Pedestrian-Motor Vehicle Collisions in Older Pedestrians," *Journal of the American Medical Association*, Vol. 288, No. 17, November 6, 2002, accessed at http://jama.ama-assn.org/issues/v288n17/rfull/joc10880.html.
34. Knoblauch, R.L., and P.D. Raymond, *The Effect Of Crosswalk Markings on Vehicle Speeds in Maryland, Virginia, and Arizona*, Report No. FHWA-RD-00-101, Federal Highway Administration, Washington, D.C., August 2000.
35. Jones, T.L., and P. Tomcheck, "Pedestrian Accidents in Marked and Unmarked Crosswalks: A Quantitative Study," In *ITE Journal,* Volume 70, No. 9, Institute of Transportation Engineers, September 2000. pp. 42-46.
36. Knoblauch, R.L., M. Nitzburg, and R.F. Seifert, *Pedestrian Crosswalk Case Studies: Sacramento, California; Richmond, Virginia; Buffalo, New York; Stillwater, Minnesota*, Report No. FHWA-RD-00-103, Federal Highway Administration, Washington, D.C., August 2001.
37. Gibby, A.R., J. Stites, G.S. Thurgood, and T.C. Ferrara, *Evaluation of Marked and Unmarked Crosswalks at Intersections in California: Final Report*, Report No. FHWA/CA/TO-94/1, California Department of Transportation, Sacramento, California June 1994.
38. Hauck, J., and L. Bates. "Well-Marked Crosswalks Are a Pedestrian's Best Friend," In *Rural and Urban Roads*, Vol. 17, No. 3, March 1979, pp. 26-28.
39. Herms, B.F., *Pedestrian Crosswalk Study: Accidents in Painted and Unpainted Crosswalks*, San Diego, California, August 1970.
40. Herms, B.F., "Pedestrian Crosswalk Study: Accidents in Painted and Unpainted Crosswalks," In *Highway Research Record 406*, Highway Research Board, National Research Council, Washington, D.C., 1972, pp. 1-14.
41. Retting, R.A., R. Van Houten, L. Malenfant, J. Van Houten, and C. Farmer, *Special Signs and Pavement Markings Improve Pedestrian Safety*, In *ITE Journal,* Volume 66, No. 12, Institute of Transportation Engineers, December 1996.
42. Bacquie, R., D. Egan, and L. Ing, *Pedestrian Refuge Island Safety Audit*, Paper presented at the ITE Spring 2001 Conference, Institute of Transportation Engineers, Washington, D.C., March 2001.
43. Britt, J.W., A.B. Bergman, and J. Moffat, "Law Enforcement, Pedestrian Safety, and Driver Compliance with Crosswalk Laws: Evaluation of a Four-Year Campaign in Seattle," In *Transportation Research Record 1485*, Transportation Research Board, National Research Council, Washington, D.C., 1995, pp. 160-167.

44. Lalani, N., “Alternative Treatments for At-Grade Pedestrian Crossings,” Informational Report, Pedestrian and Bicycle Council Task Force Committee, Institute of Transportation Engineers, Washington D.C, August 2001.
45. “Year 2 Field Evaluation of Experimental ‘In-Street’ Yield to Pedestrian Signs,” City of Madison, Wisconsin, U.S.A., 1999 (Submitted to FHWA).
46. *Pedestrian Facilities Guidebook,* Prepared by OTAK for Washington State Department of Transportation, Puget Sound Regional Council, County Road Administration Board, Association of Washington Cities, 1997.
47. Van Houten, R., J.E.L. Malenfant, and D. McCusker, “Advance Yield Markings Reduce Motor Vehicle/Pedestrian Conflicts at Multi-lane Crosswalks with an Uncontrolled Approach,” Center for Education and Research in Safety, Halifax Regional Municipality, Presented at the Transportation Research Board Annual Meeting, Washington D.C., 2000.
48. “Innovative Traffic Control Technology and Practice Europe,” Report No. FHWA-PL-00-021, Federal Highway Administration, Washington D.C., August 1999.
49. The Highway Code, Road Traffic Act, Department of Environment, Transport and the Regions, The Stationery Office, London, U.K., 1998.
50. Habib, P., “Pedestrian Safety: The Hazards of Left-Turning Vehicles,” *ITE Journal,* Institute of Transportation Engineers, Washington D.C., Volume 50, No. 4, April 1980.
51. Kittle, C., “Fluorescent Yellow Green Warning Signs for Pedestrians, School and Bicycle Crossings,” *APWA Reporter*, American Public Works Association, Washington D.C., July 2000.
52. Lalani, N., “Road Safety at Pedestrian Refuges,” *Traffic Engineering and Control*, London, U.K., September 1977.
53. “The Use of Anti-skid Surface Dressing as An Accident Remedial Measure,” Report No. ATWP 56, London Accident Analysis Unit, London Research Centre, London, U.K., June 1978.
54. Lalani, N., “Are Pelican Crossings Safe?” *Greater London Intelligence Bulletin*, Greater London Council, London, U.K., December 1975.
55. Huang, H., R. Hughes, and C. Zegeer, “An Evaluation of the LightGuard™ Pedestrian Crosswalk Warning System,” Highway Safety Research Center and M. Nitzburg Center for Applied Research, Florida Department of Transportation, Safety Office, Tallahassee, Florida, June 1999.
56. “In-Pavement Flashing Lights at Crosswalks,” TENC-98003 Informational Report, Traffic Engineering Council Committee, Institute of Transportation Engineers, Washington D.C., February 2001.
57. Godfrey, D., and T. Mazzella, *Kirkland’s Experience with In-Pavement Flashing Lights at Crosswalks*, Presented at the ITE/IMSA Annual Meeting, Lynnwood, Washington, February 8, 1999, http://www.ci.kirkland.wa.us/depart/pw/transportation/flscrswk.htm, accessed July 2005.
58. Lalani, N., “Street Lighting Improvements on Major Sections of Principal Roads in Greater London,” *Road Safety Studies Bulletin*, Greater London Council, London, U.K., April 1980.
59. Van Houten, R., and J.E.L. Malenfant, “The Influence of Signs Prompting Motorists to Yield 50 Feet before Marked Crosswalks on Motor Vehicle-Pedestrian Conflicts at

Crosswalks with Pedestrian Activated Flashing Lights," *Accident Analysis and Prevention* 24, 1992, pp. 217-225.
60. Ewing, R., "Traffic Calming, State of the Practice," Report No. FHWA-RD-135, Institute of Transportation Engineers under contract with Department of Transportation, Federal Highway Administration, Washington D.C., 1999.
61. *Canadian Guide to Neighbourhood Traffic Calming*, Transportation Association of Canada, Ottawa, Canada, December 1998.
62. "Tactile Markings for Segregated Shared Use by Bicyclists and Pedestrians," Traffic Advisory Leaflet 4/90, Traffic Advisory Unit, U.K. Department of Transport, London, U.K., December 1990.
63. Guidance on the Use of Tactile Pavement Surfaces," Department of Environment, Transport and the Regions, Scottish Office, Edinburgh, Scotland, 1998.
64. Savil, T., G. Davies, A. Fowkes, and B. Simms, "Trials on Platform Edge Tactile Surfaces," Transport Research Laboratory, Crowthorne, Berkshire, U.K., 1996.
65. Savil, T., J. Stone, and G. Whitney, "Can Older Vision Impaired People Remember the Meanings of Tactile Surfaces Used in the United Kingdom?" Transport Research Laboratory, Crowthorne, Berkshire, U.K., 1998.
66. "Report of the Fundamental Research on Standardization Relation to Tactile Tiles for Guiding the Visually Impaired," Japanese Ministry of International Trade and Industry, National Institute for Technology and Evaluation, Tokyo, Japan, 1998.
67. Sawai, H., J. Takato, and M. Tauchi, "Quantitative Measurement of Tactile Contrast Between Dot and Bar Lines Used to Constitute Tactile Pathway for the Blind and Visually Impaired Independent Travelers," Proceedings of the 9th International Mobility Conference, Decatur, Georgia, 1998.
68. Bentzen, B.L., J.M. Barlow, and L. Tabor, "Detectable Warnings: Synthesis of U.S. and International Practice," U.S. Access Board, Washington, D.C., 2000.
69. Hauger, J.S., M.P. Safewright, J.C. Rigby, and W.J. McAuley, "Detectable Warnings Project: Report of Field Tests and Observations," Final Report to U.S. Architectural and Transportation Barriers Compliance Board, Blacksburg, Virginia, Virginia Polytechnic Institute and State University, Virginia, 1994.
70. Hughes, R.G., "A Florida DOT Field Evaluation of Tactile Warnings in Curb Ramps: Mobility Considerations for the Blind and Visually Impaired," University of North Carolina, Highway Safety Research Center, Chapel Hill, North Carolina, 1995.
71. "Audible and Tactile Signals at Pelican Crossings," Department of Environment, Transport and the Regions, Traffic Advisory Unit, Leaflet 4/91, London, U.K., November 1991.
72. "The Use of Puffin Pedestrian Crossings," Network Management Advisory Leaflet, Network Management and Driver Information Division, Department of Transport, The Stationery Office, London, U.K., March 1993.
73. "Toucan, an Un-Segregated Crossing for Pedestrians and Bicyclists," Traffic Advisory Leaflet 10/93 Traffic Advisory Unit, Department of Transport, The Stationery Office, London, U.K., 1993.
74. "Toucan Crossing Development," Traffic Advisory Leaflet 4/98, Traffic Advisory Unit, Department of Transport, The Stationery Office, London, U.K., 1998.

75. Harpst, T., "Salt Lake City's Pedestrian Program," *Westernite*, District 6, Institute of Transportation Engineers, Washington D.C., November-December 2002.
76. *Pedestrian Safety Guidelines*, Department of Public Works, City of Sacramento, California, January 2003.
77. "Signs Alleviate Long-Term Crosswalk Safety Problem," *Public Works Magazine,* Public Works Journal Corporation, Ridgewood, New Jersey, February 2003.
78. Ercolano, J.M., "The Case for Strengthening New York State's Yield-To-Pedestrian Law," New York Department of Transportation, Albany, New York, 2002.
79. Slack, K., "Signalized Intersection Safety Scanning Tour," Final Summary Report, Department of Transportation, Federal Highway Administration, Washington D.C., July 22, 2002.
80. Fairfax, B.W., *School-Pedestrian Crosswalk Signals at Intersections: A Quantified Evaluation of Performance,* Seattle Engineering Department, Seattle, Washington, 1974.
81. Fairfax, B.W., *Pedestrian Crossing Traffic Control Devices: An Assessment of Innovative Methods for Enhancing Pedestrian Safety at Crossings of Arterial Streets*, Prepared for the City of Tucson Department of Transportation, Tucson, Arizona, December 14, 1999.
82. Petzold, R.G., and R. Nawrocki, "Urban Intersection Improvements for Pedestrian Safety: Volume V," *Evaluation of Alternatives to Full Signalization at Pedestrian Crossings*, Report FHWA-RD-77-146, Federal Highway Administration, Washington, D.C., December 1977.
83. Hendrickson, J., *Half Signal Report*, Seattle Engineering Department, Seattle, Washington, 1988.
84. Whitlock and Weinberger Transportation, Inc., *An Evaluation of a Crosswalk Warning System Utilizing In-Pavement Flashing Lights*, April 1998, accessed at http://www.w-trans.com/xwk-report.pdf, accessed March 28, 2003.
85. Evans, D., "The Light of Your Life: In-Pavement LEDs Stop Cars and Save Lives," *Traffic Technology International,* 1999 Annual Review, Volume 5, No. 6, Surrey, United Kingdom, December 1999.
86. Katz, Okitsu & Associates, *City of Fountain Valley Illuminated Crosswalks: An Evaluation Study and Policy Recommendations*, October 2000, accessed at http://www.katzokitsu.com/peds.htm, accessed May 27, 2002.
87. Huang, H., *An Evaluation of Flashing Crosswalks in Gainesville and Lakeland*, Highway Safety Research Center, University of North Carolina, Chapel Hill, North Carolina, November 2000.
88. Van Houten, R., D. McCusker, S. Huybers, J.E.L. Malenfant, and D. Rice-Smith, "Advance Yield Markings and Fluorescent Yellow-Green RA 4 Signs at Crosswalks with Uncontrolled Approaches," In *Transportation Research Record 1818*, Transportation Research Board, National Research Council, Washington, D.C., 2002, pp. 119-124.
89. De Robertis, M., and Ridgway M., "Planning and Design of Pedestrian and Bicycle Facilities," University of California, Institute of Transportation Studies, Berkeley, California, Technology Transfer Program Seminar Course Notes, 1999.
90. Zegeer, C.V., "Design and Safety of Pedestrian Facilities," *A Recommended Practice*, Traffic Engineering Council Committee TENC-5A-5, Institute of Transportation Engineers, Washington D.C., 1998.

91. *Manual on Uniform Traffic Control Devices for Streets and Highways, Millennium edition.* U.S. Department of Transportation, Federal Highway Administration, Washington D.C., 2001.
92. *Pedestrian Safety Guidelines*, Department of Public Works, City of Sacramento, California, January 2003.
93. *Pedestrian Crossing Control Manual*, Transportation Association of Canada, Ottawa, Canada, March 1998.
94. *Manual on Uniform Traffic Control Devices,* Ontario Ministry of Transportation, Toronto, Ontario. 1976.
95. "The Assessment of Pedestrian Crossings," The Department of Transportation, The Welsh Office, The Scottish Office, The Department of the Environment for Northern Ireland, Local Transport Note 1/95, Her Majesty's Stationery Office, London, U.K., 1995.
96. *Traffic Engineering Manual*, "Chapter 4 – Pedestrians," Volume 1, 3rd Edition, VicRoads, State of Victoria, Kew, Australia, December 1999.
97. Slack, K., "Signalized Intersection Safety Scanning Tour," Final Summary Report, Department of Transportation, Federal Highway Administration, Washington D.C., July 22, 2002.
98. Department of Transport (1995) Local Transport Note 1/95 *The Assessment of Pedestrian Crossings*, Her Majesty's Stationary Office, London, U.K., 1995.
99. Department of Transport (1995) Local Transport Note 2/95 *The Design of Pedestrian Crossings*, Her Majesty's Stationary Office, London, U.K., 1995.
100. Davies, D., *Research, Development, and Implementation of Pedestrian Safety Facilities in the United Kingdom*. FHWA-RD-99-089, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1999.
101. *Manual of Uniform Traffic Control Devices for Canada* - Fourth Edition, Transportation Association of Canada, Ottawa, Canada, September 1998.
102. Ribbens, H., "Pedestrian Facilities in South Africa: Research and Practice," In *Transportation Research Record 1538*, Transportation Research Board, National Research Council, Washington, D.C., 1996, pp. 10-18.
103. STANDARDS AUSTRALIA - AS 1742.10-1990, *Manual of Uniform Traffic Control Devices, Part 10: Pedestrian Control and Protection*, North Sydney: Standards Australia, 1990.
104. *Manual of Uniform Traffic Control Devices - Part 10 Pedestrian Control and Protection*, Department of Main Roads, Queensland, Australia, Fourth Issues 1995 Edition 30th November 1995.
105. Cairney, P., *Pedestrian Safety in Australia.* FHWA-RD-99-093, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1999.
106. Carlson, P.J., and S.M Turner, *Revising the Traffic Signal Warrants to Better Accommodate Pedestrians and Cyclists.* Texas Transportation Institute Report 2136-1, Texas A&M University, College Station, Texas, 2001.
107. Zeeger, C.V., K.S. Opiela, and M.J. Cynecki. *Pedestrian Signalization Alternatives.* FHWA/RD-83/102, Federal Highway Administration, Washington, D.C., 1985.
108. Neudorff, L.G., *Candidate Signal Warrant from Gap Data*. FHWA-RD-82-152, Federal Highway Administration, Washington, D.C., 1983.

109. *Highway Capacity Manual.* Transportation Research Board, Washington, D.C., 2000.
110. United States Department of Transportation, Bureau of Transportation Statistics, 1995 Nationwide Personal Transportation Survey, Washington, D.C., 1995.
111. AASHTO, "A Policy on Geometric Design of Highways and Streets," American Association of State Highway and Transportation Officials, Washington, D.C., 2001.
112. Lieberman, E.B., G.F. King, and R.B. Goldbatt, "Traffic Signal Warrants," *NCHRP 3-20*, Transportation Research Board, National Research Council, Washington, D.C., 1976.
113. Zegeer, C.V., J.R. Stewart, H.H. Huang, and P.A. Lagerwey, *Safety Effects of Marked vs. Unmarked Crosswalks at Uncontrolled Locations: Executive Summary and Recommended Guidelines.* Publication FHWA-RD-01-075. FHWA, U.S. Department of Transportation, Washington, D.C., March 2002.
114. Malek, M., *Crosswalk Enhancement Comparison Study*. City of San Jose Department of Transportation, San Jose, California, 2001.
115. U.S. Access Board, *Draft Guidelines for Accessible Public Rights of Way.* June 17, 2002. http://www.access-board.gov/Rowdraft.htm. Accessed September 2003.
116. LaPlante, J.N., and T.P. Kaeses, "The Continuing Evolution of Pedestrian Walking Speed Assumptions." *ITE Journal.* Volume 74, No. 9. September 2004.
117. *Transportation and Traffic Engineering Handbook,* 2nd Edition. Institute of Transportation Engineers. Prentice-Hall International, Inc., Englewood Cliffs, New Jersey, 1982.
118. Knoblauch, R.L., M.T. Pietrucha, and M. Nitzburg, "Field Studies of Pedestrian Walking Speed and Start-up Time," *Transportation Research Record 1538,* Transportation Research Board, National Research Council, Washington, D.C., 1995, pp. 63-67.
119. Guerrier, J.H., and S.C. Jolibois Jr. "The Safety of Elderly Pedestrians at Five Urban Intersections in Miami." *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting,* Human Factors and Ergonomics Society, Santa Monica, California, 1998.
120. Milazzo, J.S., N.M. Rouphail, J.E. Hummer, and D.P. Allen. "Quality of Service for Interrupted-Flow Pedestrian Facilities," in *Highway Capacity Manual 2000. Transportation Research Record 1678*, Transportation Research Board, National Research Council, Washington, D.C., 1999, pp. 25-31.
121. *Traffic Control Devices Handbook,* J.L. Pline, Editor. ITE Publication IR-112. Institute of Transportation Engineers, Washington, D.C., 2001.
122. Staplin, L., K. Lococo, S. Byington, and D. Harkey, "Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians," Report No. FHWA-RD-01-051, Federal Highway Administration, McLean, Virginia, October 2001.
123. Dahlstedt, S., "Walking Speeds and Walking Habits of Elderly People," National Swedish Road and Traffic Research Institute, Stockholm, Sweden, undated.
124. Coffin, A., and J. Morrall, "Walking Speeds of Elderly Pedestrians at Crosswalks," *Transportation Research Record 1487,* Transportation Research Board, National Research Council, Washington, D.C., 1996, pp. 27-38.
125. Dewar, R., "Chapter 18: Pedestrians and Bicyclists," *Human Factors in Traffic Safety,* Lawyers and Judges Publishing Company, Tucson, Arizona, 2002.
126. Bennett, S., A. Felton, and R. Akçelik, "Pedestrian Movement Characteristics at Signalized Intersections," 23rd Conference of Australian Institutes of Transportation Research, Monash University, Melbourne, Australia, 10-12 December 2001.

127. "An Investigation of Pedestrian Movement Characteristics at Mid-Block Signalized Crossings," Technical Report, Akçelik & Associates Pty Ltd., Melbourne, Australia, December 2001.
128. Organisation for Economic Co-operation and Development (OECD), "Safety of Vulnerable Road Users," DTSI/DOT/RTR(98)1/FINALMOECD, Scientific Expert Group on the Safety of Vulnerable Road Users, Paris, France, 1998.
129. Perry, J. *Gait Analysis.* McGraw Hill, New York, New York, 1992.
130. Fambro, D.B., K. Fitzpatrick, and R.J. Koppa. Determination of Stopping Sight Distance. NCHRP Report 400, Washington, D.C., 1997.
131. U.S. Census Bureau Web Page: National Population Projections – Summary Tables (NP-T3-F) Projections of the Total Resident Population by 5-Year Age Groups, and Sex with Special Age Categories: Middle Series, 2006 to 2005. http://www.census.gov/population/projections/nation/summary/np-t3-f.txt. Accessed January 18, 2005.
132. Oxley, J.A., E. Ihsen, B.N. Fildes, J.L. Charlton, and R.H. Day. "Crossing Roads Safely: An Experimental Study of Age Differences in Gap Selection by Pedestrians." *Accident Analysis & Prevention.* Elsevier Ltd., London, England. Volume 37, 2005.
133. Sack, L., and K. Lawson. "Equations for Signal Warrants 2 and 3," ITE Traffic Engineering Council Newsletter Update. Volume 11, Issue 1. Winter 2005.