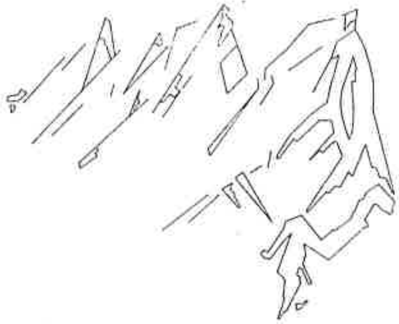
City of Boulder



PEDESTRIAN CROSSING TREATMENT WARRANTS

Prepared For:

City of Boulder Transportation Division
P.O. Box 791
Boulder, Colorado 80306

May 1996

TP-92143

TRANSPLAN ASSOCIATES, Inc.
1375 Walnut Street, Suite 211, Boulder, CO 80302
Phone (303) 442-3130 Fax (303) 442-3139

TABLE OF CONTENTS

FIGURES AND TABLES

ABSTRACT

Providing safe and efficient pedestrian facilities is a long-established goal of the City of Boulder. Pedestrian facilities are of particular importance as we try to reduce our dependency on the automobile. The decision to travel as a pedestrian is in part subject to the pedestrian's ability to safely and efficiently cross roadways along the travel route. With this in mind, a set of criteria for providing improved pedestrian crossing facilities has been developed and is contained within this text. Specifically, this document summarizes:

- A technical literature search regarding existing pedestrian crossing warrant criteria.
- The physical data needed to analyze pedestrian crossings and the results of data collection at selected locations in Boulder.
- Proposed pedestrian crossing warrant criteria and procedures for evaluating the need for pedestrian crossing improvements, including a "logic diagram" approach.
- Specific pedestrian crossing treatments that may be warranted at a given pedestrian crossing location.

The pedestrian crossing treatment warrants developed in this document are intended to provide a consistent procedure for considering the need for crossing improvements and the type of crossing treatments appropriate where needed on a case-by-case basis in the City of Boulder. Implementation of crossing treatments will require funds that could potentially have been spent on other transportation system improvements and, therefore, must be considered carefully in the funding allocation process. Staff should coordinate the installation of pedestrian crossing treatments with other projects and programs (such as the Greenways Program) or ongoing construction projects to insure that the greatest improvement for pedestrians and bicyclists can be achieved within the limits of available funding.

1. BACKGROUND

Roadway crossings can be barriers to pedestrian travel. The decision to travel as a pedestrian is in part dependent upon the ability to safely and efficiently cross roadways along the pedestrian's intended travel route. The City of Boulder wants to encourage pedestrian travel by providing safe and efficient roadway crossing opportunities. There are a variety of methods available to help facilitate pedestrian crossings on busy roadways, including marked crosswalks, neckdowns, median refuges, and traffic signals.

Signalized traffic control measures to reduce pedestrian-vehicle conflicts typically increase delays for both pedestrian and vehicular traffic. This creates a conflict between providing safety and generating operational efficiency for all modes of travel. It is the goal of this project to create a set of pedestrian crossing warrants tailored to meet the needs of the City of Boulder by optimizing safety and minimizing delay. The warrant criteria will provide a framework for identifying locations where pedestrian crossing treatments are appropriate and should be implemented by the City. The warrants apply to urban, suburban and residential areas with speed limits of 40 mph or less. The warrant criteria do not apply to school crossings or to existing protected pedestrian crossings. A protected pedestrian crossing has a traffic control device, such as a stop sign or a traffic signal, which regulates automobile traffic and protects pedestrians in the crosswalk. The warrant criteria contained in this document applies to improvements to crossings which are currently unprotected.

The City's goals for pedestrian crossing treatments include the following:

- Promote pedestrian travel by providing safe and efficient roadway crossing opportunities.
- Reflect the needs of the diverse range of pedestrian age and ability groups in the City.
- Provide for a balance between the pedestrian travel demand and the City's ability to implement pedestrian crossing treatments City-wide.
- Achieve a reasonable balance of impacts on all modes of travel using the City's transportation system.
- Encourage multi-use path crossings of collector, minor arterial and principal roadways where they can be safely implemented.
- Create a standard guideline to ensure consistent and appropriate installation of pedestrian treatments throughout the City.

2. EXISTING PEDESTRIAN CROSSING WARRANT CRITERIA

Upon beginning the process of determining pedestrian crossing warrant criteria, an extensive review of the available technical literature was conducted. Summaries of relevant reports are included in Appendix 2. A variety of crossing warrant criteria was reported in the literature and is summarized below.

The Manual on Uniform Traffic Control Devices (MUTCD) is the national standard for establishing traffic control on roadways throughout the United States and it has been adopted by the City of Boulder as the City standard. The pedestrian crossing warrant criteria established by the MUTCD states that a traffic signal may be warranted where:

- Pedestrian volume crossing the major street during an average day is 100 or more pedestrians for each of any four hours, or 190 or more during any one hour.

- The required pedestrian volumes given above may be reduced by as much as 50 percent when the pedestrian crossing speed is below 3.5 feet per second. This is likely to apply at locations with high concentrations of elderly, handicapped or young pedestrians.

- In addition to the minimum pedestrian volume requirement, there must be less than 60 gaps per hour in the traffic stream that are of adequate length for pedestrians to cross the street during the same period that the pedestrian volume criterion is satisfied. Where there is a divided street with a median of sufficient width for the pedestrian(s) to wait, the requirement applies separately to each direction of vehicular traffic.

- Where coordinated traffic signals on each side of the study location provide for platooned traffic which result in fewer than 60 gaps per hour of adequate length for the pedestrians to cross the street, a traffic signal may not be warranted.

- This pedestrian crossing warrant applies only to those locations where the nearest traffic signal on the major street is more than 300 feet away and where a new signal at the study location would not unduly restrict platooned flow of traffic.

In addition, the MUTCD established the following warrant criteria for a signalized school crossing: A traffic control signal may be warranted at an established school crossing when the number of adequate gaps in the traffic stream during the period when the children are using the crosswalk is less than the number of minutes in the same period. It is typically very difficult to justify a signal based on either the pedestrian volume warrant or the school crossing warrant.

The pedestrian warrant included in the MUTCD is perhaps the most controversial of all the signal warrants. According to the Federal Highway Administration's report on pedestrian signalization alternatives (July 1985), "The existing [1978] MUTCD Minimum Pedestrian Volume Warrant is highly impractical for most real-world conditions and is largely ignored by the traffic engineering community." This report developed alternative warrant criteria based on minimum pedestrian volumes crossing the major street for either four hours (60 or more pedestrians per hour), two hours (90 or more pedestrians per hour), or one peak hour (110 or more pedestrians per hour) combined with less than 60 acceptable gaps per hour during the same period. This criteria is based on accident statistics which showed a breakpoint in pedestrian volume as compared to mean pedestrian accidents at a daily pedestrian volume level of 1,200 at signalized intersection locations.

The 1985 FHWA report also included a special traffic signal warrant to accommodate elderly and/or handicapped pedestrians at locations meeting the following conditions: The location is at least 150 feet from a protected crossing. The number of elderly (60 years of age or older) and/or handicapped pedestrians is at least 30 or more for each of any four hours, 45 or more for each of any two hours, or 60 or more per hour in the peak hour. During the hour that pedestrian volume is the highest, there must be less than 60 adequate gaps in the vehicle stream. Walking speeds of 2.5 feet per second should be used when computing adequate gap time, according to this report.

In 1977, King developed a pedestrian signal warrant based on pedestrian delay, as reported in the Transportation Research Record 629. This warrant incorporated the following considerations: an acceptable level of average pedestrian delay; a tolerable level of maximum pedestrian delay (i.e., 95th percentile); and an equitable allocation of total delay between the pedestrian and vehicle components of the traffic stream. The study established an acceptable mean pedestrian delay of 30 seconds and 60 seconds as a tolerable level of maximum (95th percentile) delay.

Since the use of signals is not considered appropriate for extremely low pedestrian levels, a lower limit of pedestrian hourly demand was set at an aggregate pedestrian delay of one hour per hour, and a minimum pedestrian volume of 100 per hour. The numerical warrants for undivided and divided highway locations are presented in Figures 1 and 2. The minimum pedestrian volume that warrants a signal is read from the appropriate chart; a signal is warranted if the actual pedestrian volume exceeds this value. Before signals are installed, these warrants should be met or exceeded for four hours on an average weekday.

The Ottawa-Carleton Transportation Department (Canada) uses pedestrian crossovers to facilitate pedestrian crossings on major roadways. A pedestrian crossover in Canada consists of a crosswalk and a flashing amber beacon which is activated by the pedestrian. When the beacon is flashing, vehicles are required to stop and let the pedestrian cross the street. They have found this device to incur less vehicular delay than a traffic signal.

The installation of a pedestrian crossover is warranted when the proposed location plots for pedestrian delay and pedestrian volume are within the warranted zone on both of their graphs, shown in Figures 3 and 4. In addition, the following criteria must be met:

- There must be at least 200 weighted pedestrian crossings in an eight hour period. A factor of two is applied to senior citizens and children under 12 years of age who are unassisted by school patrol, school crossing guards, or police.
- The location must be located more than 180 m (600 ft) from adjacent traffic control signals or pedestrian crossovers.
- The 85th percentile speed on the roadway is less than 65 km/hr (40 mph) off peak.
- The roadway is undivided with a width that is not greater than four traffic lanes for a two-way street or three lanes wide for a one-way street.
- Vehicular volumes must be less than 15,000 during a 12 hour period (7:00 a.m. to 7:00 p.m.).
- There are no existing visibility problems due to horizontal or vertical roadway alignment or objects.

Figure 1: Proposed Pedestrian Signal Warrant for an Undivided Highway (King)

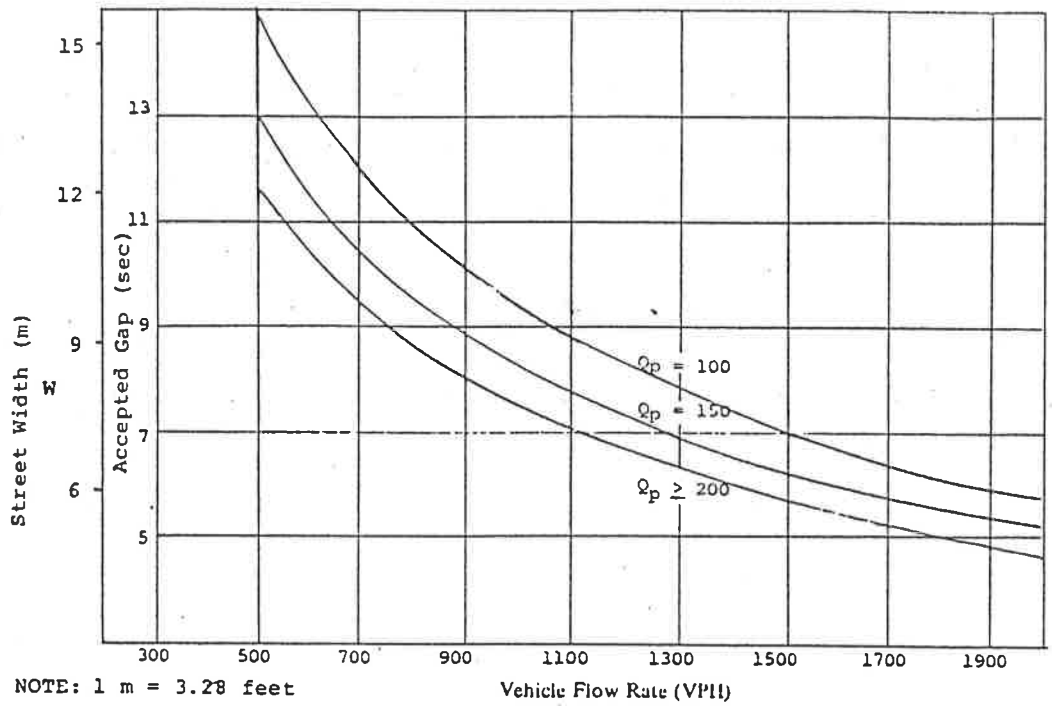


Figure 2: Proposed Pedestrian Signal Warrant for a Divided Highway (King)

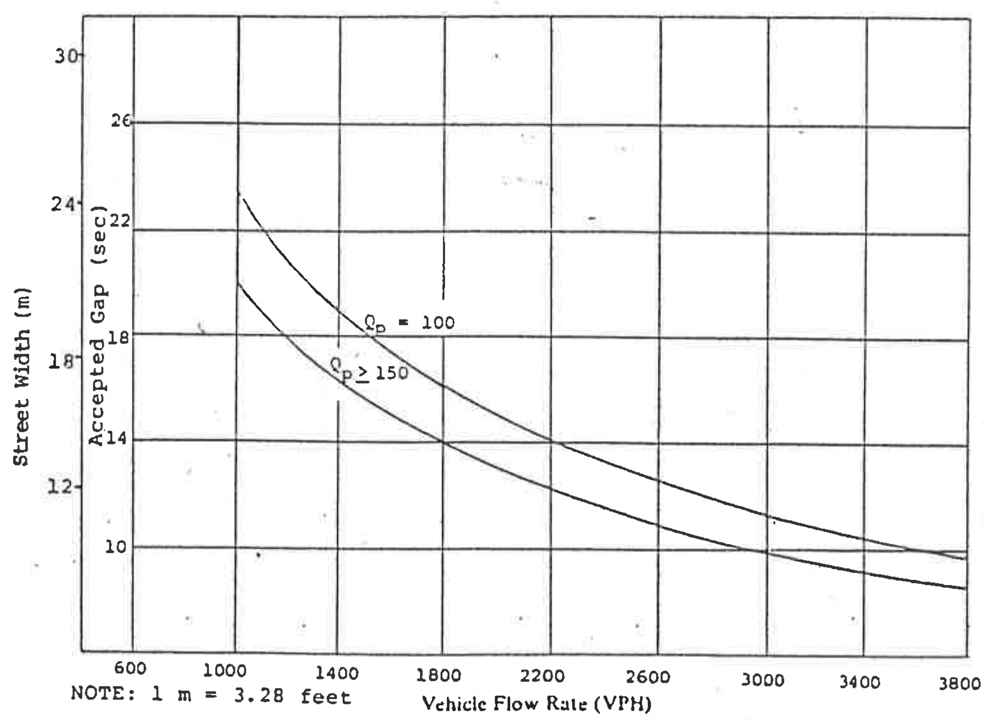


Figure 3: Graph for Pedestrian Crossover Evaluation [Pedestrian Volume] (Henderson and Ross)

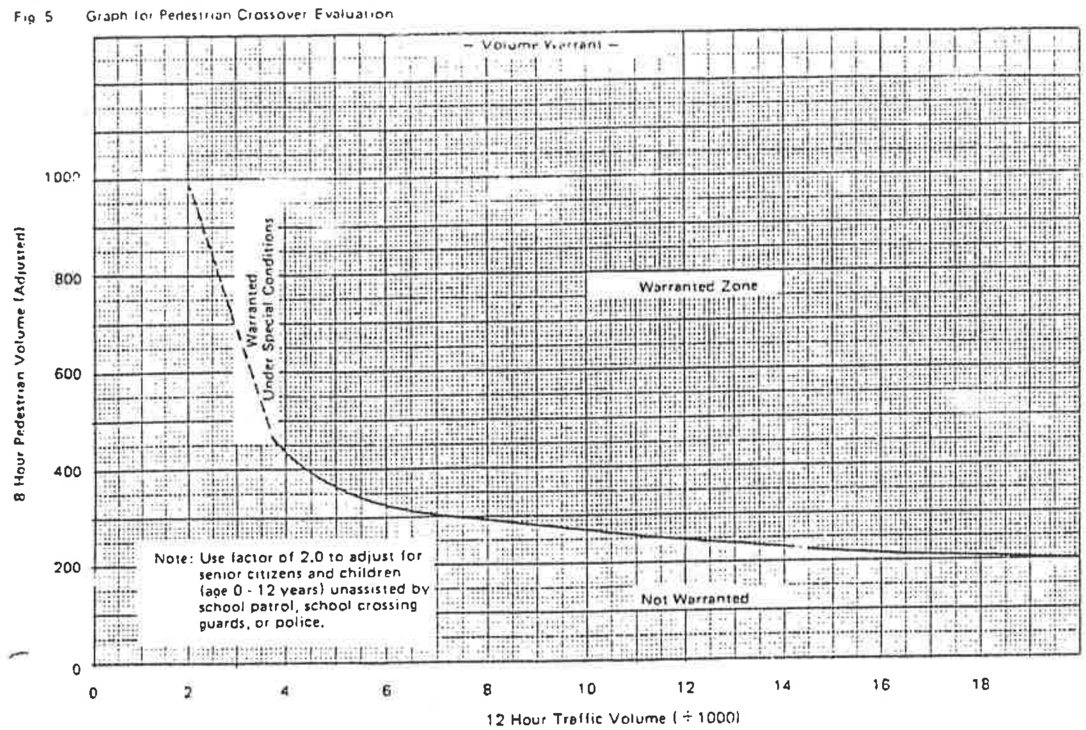
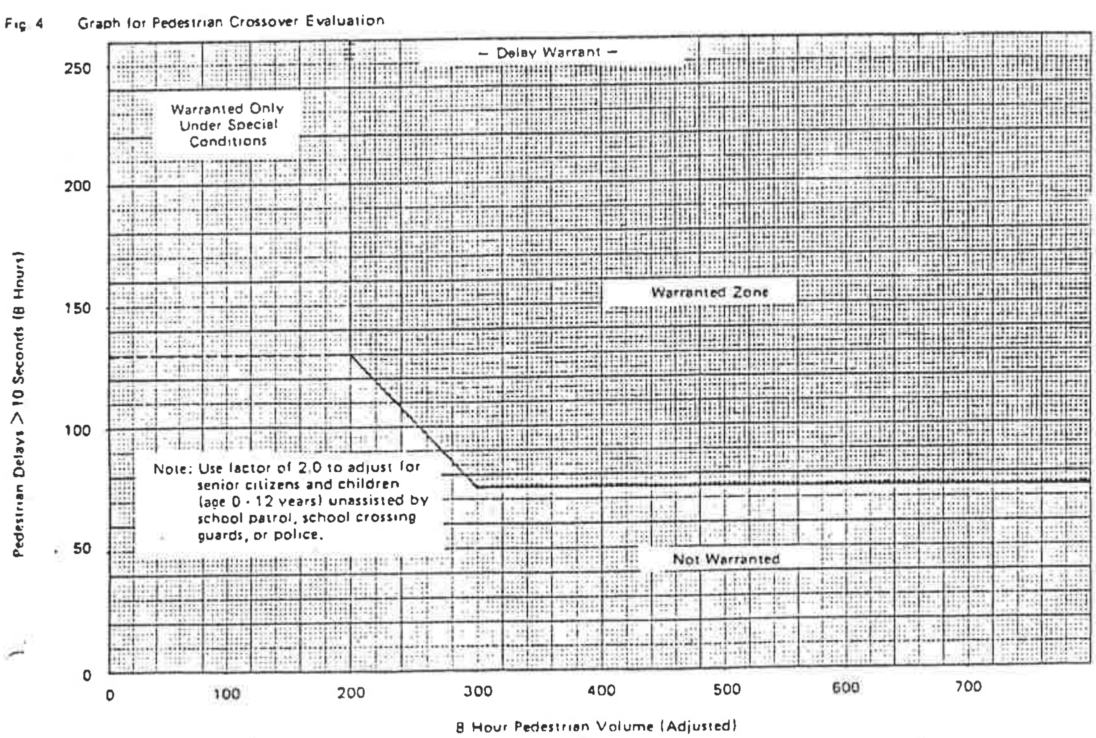


Figure 4: Graph for Pedestrian Crossover Evaluation [Pedestrian Delay] (Henderson and Ross)



- Offset intersections, pedestrian visibility problems, roadside distractions or heavy turning movements are not present.

- A consistent violation of the stopping prohibition is not be expected.

- A constant interruption of vehicular traffic would not occur.

- Sidewalks necessary for the safe and effective use of a pedestrian crossover are available or will be provided prior to a pedestrian crossover being installed.

Pedestrian crossovers have been used successfully within the United States. The City of Los Angeles, California uses flashing red signals at mid-block pedestrian crossings.[Hensen] The first use of mid-block crossings occurred in downtown Los Angeles where the blocks are 660 feet long. Approximately thirty years ago, they installed mid-block crosswalks to focus the pedestrians. These locations were enhanced later with flashing beacons. Apparently, these efforts were not effective because the City decided twenty years ago to install signals at these locations. At the time, these streets were two-way and the mid-block locations created signal progression conflicts. Their solution was to make the red phase flashing to minimize the delays. Over the years, the City has found that the flashing operation works well and they have installed them at locations outside of the central business district with good results.

Ribbens and Bahar developed proposed warrants for South-African uncontrolled mid-block pedestrian crossings in their report for the National Institute for Transport and Road Research, published in 1982. Prior to their study, signalized control at mid-block crossings was warranted when the number of pedestrians crossing a street during each of any four hours of a normal day exceeded 200 per hour at locations farther than 150 meters (492 feet) from any signal controlled pedestrian crossing and the vehicular traffic volume in both directions exceeded 400 vehicles per hour during each of the same four hours.

The warrant proposed by Ribbons and Bahar incorporated a minimum pedestrian volume and a minimum vehicular volume (as shown in Table 1) and a maximum pedestrian volume based on the delay incurred to vehicular traffic. The maximum pedestrian volumes were established because as pedestrian volumes increase vehicular delay also increases. Pedestrians create a serious interruption to traffic when the uncontrolled mid-block crossing is available to vehicular traffic less than 60% of the time. The authors stated that at this point, the crossing should be signalized.

As mentioned above, it is extremely difficult to qualify for a pedestrian signal under the existing MUTCD warrant criteria. Although the MUTCD standard is the established criteria for warranting pedestrian signals in the United States, there is disagreement in the literature regarding its applicability and usefulness. The following sections examine the critical components associated with establishing pedestrian crossings, report on field data collected within Boulder, and incorporate available research into the development of warrants for pedestrian crossing treatments for the City of Boulder.

Table 1: Minimum Vehicular and Pedestrian Volumes Per Hour (Ribbons and Bahar)

Speed Limit	Effective Road Width	Direction of Traffic Flow	Min Veh Vol (vph)		Min Ped Vol (vph)	
			Typical	Elderly	Typical	Elderly
60 km/hr (37 mph)	7 m (23 ft)	one-way	850	749	98	97
		two-way	705	620	96	95
	10 m (33 ft)	one-way	612	522	95	93
		two-way	[illegible]	449	93	[illegible]
	14 m (46 ft)	one-way	424	353	91	89
		two-way	365	308	89	87
70 km/hr (43.5 mph)	7 m	one-way	797	705	97	96
		two-way	637	571	95	94
	10 m	one-way	579	496	94	93
		two-way	484	419	92	91
	14 m	one-way	404	335	91	88
		two-way	342	289	89	87

NOTE: The data in the above table is based on pedestrian walking speeds of 1.37 m/sec (4.5 ft/sec) for standard pedestrians and 1.18 m/sec (3.87 ft/sec) for elderly pedestrians.

3. CRITICAL PEDESTRIAN CROSSING WARRANT COMPONENTS

The main rationale underlying the creation of a pedestrian crossing warrant is to determine traffic flow conditions characterized by inadequate gaps in the traffic stream which affect the safe passage of pedestrians crossing the street. Critical components to be considered in the determination of pedestrian crossing warrants and the evaluation of pedestrian crossings are listed below and described in the following sections:

- Pedestrian walking speed
- Pedestrian and bicycle volumes
- Distance to the nearest protected crossing
- Pedestrian delay
- Acceptable gaps in the vehicle traffic stream
  - Vehicle volume
  - Crossing distance / lane configuration

A. PEDESTRIAN WALKING SPEEDS

The standard pedestrian walking speed used for engineering design is 4 ft/sec, as prescribed by the MUTCD. According to the Institute of Transportation Engineers (ITE) Handbook, many pedestrians (especially the elderly) walk at a slower speed. Estimates from ITE studies suggest that the average pedestrian walking speed is 3.7 feet per second, with 35 percent of pedestrians walking more slowly than the four feet per second design standard. Pedestrian walking speeds are influenced by the following factors:

- Density, gender, and size of the group: Speed is reduced in higher-density conditions and when pedestrians walk in pairs as compared to walking alone.

- Weather conditions: Walking speeds are likely to be slowed under winter conditions with snow and heavy footwear.

The MUTCD states that the pedestrian signal warrant criteria may be modified when the predominant pedestrian walking speed is less than 3.5 feet per second. This may be the case where there is a preponderance of elderly, handicapped or young pedestrians. Handicapped pedestrians include not just those with physical problems, such as restricted mobility or perception, but also those temporarily disabled because they are encumbered by carrying luggage, packages, children and so forth.

Field data was collected within the City of Boulder to compare Boulder's pedestrian walking speeds to the published standards. The data yielded the following pedestrian walking speeds:

Table 2: Boulder Pedestrian Walking Speeds

	Average Adult Pedestrian	Elderly/Handicapped Pedestrian
15th Percentile	4.0 ft/sec	3.5 ft/sec
85th Percentile	6.0 ft/sec	4.5 ft/sec

The 15th percentile walking speed represents the conservative end of the spectrum while the 85th percentile incorporates faster, more daring pedestrians. When the 15th percentile pedestrian is accommodated by the design standard, the majority of pedestrians will feel comfortable crossing the street. The Boulder field data substantiates the average adult pedestrian walking speed design standard of 4 feet second, with a slower walking speed for elderly pedestrians. The following sections use the 15th percentile pedestrian walking speed in developing the warrant criteria.

B. PEDESTRIAN VOLUME

The MUTCD requires a minimum pedestrian volume of 100 or more pedestrians for four hours or 190 or more pedestrians for one hour. As previously discussed, it is extremely difficult to meet this warrant criteria. Other studies have recommended the following minimum pedestrian crossing volumes:

- FHWA Pedestrian Signalization Alternatives (July 1985) recommends the following minimum pedestrian volumes in their pedestrian crossing warrant:

  60 pedestrians per hour for four hours
  90 pedestrians per hour for two hours
  110 pedestrians per hour for one hour

  The minimum pedestrian volume recommendation is revised as follows to accommodate elderly and/or handicapped pedestrians:

30 pedestrians per hour for four hours
45 pedestrians per hour for two hours
60 pedestrians per hour for one hour

- King's pedestrian signal warrant, which is based on pedestrian delay, requires a minimum pedestrian volume of 100 pedestrians per hour.

- The Ottawa-Carleton (Canada) Department of Transportation pedestrian crossover warrant criteria requires a minimum of 200 pedestrian crossings in an eight hour period, with a minimum range of 200 to 400 pedestrians on roadways with 12 hour traffic volumes ranging from 4,000 to 15,000, respectively. Each elderly or young pedestrian is counted as two pedestrians for the pedestrian volume calculation.

- The recommended minimum pedestrian volumes for an unsignalized mid-block crossing in South Africa range between 85 and 100 pedestrians per hour for corresponding vehicle volumes ranging from 335 to 850 vehicles per hour.

The MUTCD requirement is too high to adequately accommodate pedestrians in Boulder, given the City's goal of providing a sense of safety for pedestrians and reducing dependency on the automobile. In consideration of the alternate pedestrian volume warrant criteria discussed above, the Boulder warrant criteria requires a minimum pedestrian volume of 100 pedestrians per hour for a peak hour or 50 pedestrians per hour for four hours. Each elderly, handicapped or young pedestrian is counted as two pedestrians for the pedestrian volume calculation.

In support of Boulder's advocacy of pedestrian travel, if a pedestrian crossing is located at a location with overriding need (i.e., multi-use path, bike corridor, transit access) the minimum pedestrian volume criteria may be waived. Engineering judgment must be used when evaluating overriding need. For example, pedestrian crossings should not be provided at every bus stop. However, if lack of a pedestrian crossing inhibits area-wide use of the bus system, then perhaps a crossing should be considered at an appropriate location. Advocacy

In addition, if there are inadequate gaps to accommodate bicycle crossings, then the bicycle volume should be included in the pedestrian volume count. A separate gap calculation for bicycles will need to be completed at locations with significant bicycle traffic (20% of crossing volume or more) (see Section 3F)).

C. DISTANCE TO NEAREST PROTECTED CROSSING

The MUTCD pedestrian crossing warrant requires a minimum distance of 300 feet to the nearest traffic signal on the major street. Locations with protected pedestrian crossings located nearer than 300 feet do not warrant crossing protection.

The MUTCD also stipulates that a new signal must not unduly restrict platooned flow of vehicular traffic. This criteria is not included in Boulder's pedestrian crossing warrant. However, if a pedestrian signal will restrict platooned traffic flow, the pedestrian signal will be coordinated with the surrounding signal system. This will maximize the safety and efficiency of the system for both pedestrians and vehicles.

D. PEDESTRIAN DELAY

Pedestrian delay indicates the amount of time a pedestrian must wait before crossing the street. The MUTCD allows a 60 second pedestrian delay. However, research conducted by Ribbens and Bahar indicated that pedestrians become impatient after waiting 30 seconds to cross the street. Warrant criteria for the Ottawa-Carleton Department of Transportation (Canada) establishes its warrant criteria for pedestrian delays greater than 10 seconds.

Field data collected in Boulder indicates that pedestrians are willing to wait an average of 15 seconds before crossing the street, with an 85th percentile value of 22 seconds. This statistic was determined by measuring the pedestrian delay for individuals who waited for an adequate gap and eventually crossed the street through a gap that was shorter in length than one or more gaps that were previously rejected. Crossing in the smaller gap indicated a level of impatience had been achieved and the pedestrians were willing to take a risk that was previously unacceptable to them.

E. VEHICLE VOLUME - AVAILABLE GAPS

Gap is defined as the amount of time that elapses from the point when the rear of a vehicle passes a spot on a roadway until the front of the next arriving vehicle (from either direction) passes that same spot. The minimum adequate gap for a pedestrian to cross a street is a function of crossing distance, walking speed, predominant number of rows in the group, time headway between rows, and the group start-up time. Pignataro supplies this standard formula:

$$G = W/S + (N-1)*H + R$$

G = minimum safe gap in traffic, seconds
W = crossing distance or roadway width, feet
S = walking speed (ft/sec)
N = predominant number of rows (group size, typically 1 in Boulder)
H = time headway between rows, seconds (standard value H = 2 sec)
R = pedestrian start-up time, seconds (standard value R = 3 sec)

By definition, an adequate gap will be of sufficient length to accommodate safe crossing of 85 percent of the pedestrians when the 15th percentile pedestrian walking speed is used in the calculation. According to Pignataro, pedestrians will alter their walking speed depending upon the closeness of vehicles when crossing the street. Mean walking speeds varied from 6.4 feet per second when the gap before the arrival of the next car was 2 seconds to 3.8 feet per second when the gap was 9 seconds or more. When the exact pedestrian walking speed is unknown, it is acceptable to use the standard design value of 4 feet per second for the pedestrian walking speed. Table 3 may be used to determine the adequate gap for pedestrian crossings of a given distance; the values in the table are based on the equation shown above (with the assumptions that N =1 and R = 3).

The MUTCD requires less than 60 adequate gaps per hour in order to meet its pedestrian crossing warrant criteria. However, based on the pedestrian delay criteria discussed above, the proposed warrant criteria for Boulder recommends 120 adequate gaps per hour (averaging one acceptable gap every 30 seconds) as a minimum. Locations with more than 120 gaps per hour would not meet the warrant criteria.

Vehicle volume and roadway geometry affect the number of available adequate gaps on a given roadway. Gaps must be measured considering all lanes and directions of traffic. The following equation may be used as a preliminary step in determining if the crossing location warrants a gap study. It was developed from a cross section of Boulder field data (traffic volumes and crossing distances) with a range of available adequate gaps.

$$[ADT]*[Crossing\ Distance\ (ft)] / 1000 > 200$$

When the result is greater than 200, a gap study should be conducted to determine the number of available adequate gaps. When the result is less than 200, it is likely that a gap study will show that there are sufficient adequate gaps to accommodate pedestrian crossings and further analysis is not required.

When gap data is collected, the traffic should be visually observed to assess the level of vehicular congestion with respect to the data. If gaps are recorded in the data as a result of queued traffic that is stopped, then that condition should be noted. However, pedestrians would be able to cross in front of the stopped vehicles when traffic is backed up, particularly if there is a median with a marked crosswalk, so the gap data would be valid.

Table 3: Adequate Gaps for Pedestrian Crossings

Crossing Distance	Adequate Gap (sec)		Crossing Distance	Adequate Gap (sec)	
	Average Adult (4.0 ft/sec)	Elderly/Hand. (3.5 ft/sec)		Average Adult (4.0 ft/sec)	Elderly/Hand. (3.5 ft/sec)
12 ft	6.0	6.4	60 ft	18.0	20.1
20 ft	8.0	8.7	70 ft	20.5	23.0
24 ft	9.0	9.9	72 ft	21.0	23.6
30 ft	10.5	11.6	80 ft	23.0	25.9
36 ft	12.0	13.3	84 ft	24.0	27.0
40 ft	13.0	14.4	90 ft	25.5	28.7
48 ft	15.0	16.7	96 ft	27.0	30.4
50 ft	15.5	17.3	100 ft	28.0	31.6

The MUTCD states that if a roadway has a median of at least four feet, the pedestrian crossing for each direction of traffic should be considered as two separate movements since the median provides a pedestrian refuge. However, since a four foot median does not provide a sufficient level of comfort and security for the 15th percentile pedestrian, this Boulder warrant criteria recommends that the pedestrian crossing distance should be considered as two separate movements only when the median width is six feet or more. For design purposes, a median width of six feet is the minimum acceptable width. However, a median width of eight feet is preferred because it provides more protection to the pedestrians, refuge from splash, and more space to shelter a bicycle.

F. BICYCLES

If there is a significant amount of bicycle traffic (defined as 20% of crossing traffic or more) at the pedestrian crossing location being evaluated, then bicycle data should be included in the warrant analysis. A gap study should be completed for the bicycles and if there are fewer than 120 adequate gaps in the vehicular traffic stream then the bicycle volume should be added to the pedestrian volume for the warrant analysis.

During data collection, bicyclists who dismount and walk their bikes across the street should be counted as pedestrians. Only bicyclists who ride across the street should be included in the additional bicycle gap analysis. Based on bicycle crossing speed data collected at selected locations in Boulder, a bicycle crossing speed of 10 feet per second should be used to determine the minimum acceptable gap required for bicycles.

4. WARRANT CRITERIA

The warrant criteria established in the previous sections is applicable to roadways in urban, residential or suburban areas with speed limits less than 40 mph. This section incorporates criteria recommendations specific to Boulder. A description of the procedures and a detailed pedestrian crossing warrant flow chart are included in Section 6.

A. MINIMUM PEDESTRIAN VOLUME

The pedestrian crossing volume for the major street must be at least 100 pedestrians per hour for any one (peak) hour or 50 pedestrians per hour for any four hours, unless the crossing is on a designated multi-use path. The pedestrian crossing volume includes all pedestrians crossing the major street at the crossing location (i.e., both sides of the street at an intersection).

B. DISTANCE TO NEAREST PROTECTED CROSSING

The nearest protected pedestrian crossing must be greater than 300 feet away from the pedestrian crossing location being evaluated. Protected pedestrian crossings include traffic signals with pedestrian indications and grade separated crossings. or stop signs?

C. MINIMUM ACCEPTABLE GAPS

There must be less than 120 acceptable gaps in the vehicle traffic stream during the hour(s) when the crossing meets the pedestrian volume criteria.

Even a need d

D. PERMITTED MODIFICATIONS TO THE WARRANT CRITERIA

All of the above criteria must be met in order to warrant a pedestrian crossing treatment. Modifications to the criteria may be made for the following situations:

- The pedestrian volume requirement may be waived at crossing locations with overriding need, such as where multi-use paths, bike corridors, or transit access require pedestrian crossings of a busy roadway as discussed in Section 3B. This supports Boulder's pedestrian advocacy position.

overrid Need.

- A walking speed of 3.5 feet per second should be used for gap calculations at locations with twenty percent or more handicapped, elderly or young pedestrians.

- If there are inadequate acceptable gaps to accommodate bicycle crossings, the bicycle volume should be added to the pedestrian volume for the warrant analysis. A 10 feet per second crossing speed should be used to determine the minimum acceptable gap for bikes.

- Each elderly, handicapped or young pedestrian should be counted as two pedestrians for the pedestrian volume calculation.

- Roadways with a median width of at least six feet should be evaluated as two separate crossings since the median allows pedestrians to take refuge and conduct the crossing in two parts. A six foot median is just wide enough to protect pedestrians from splash and shelter a bicycle, if necessary. If pedestrians crossing only one of the two directions meet the pedestrian crossing warrant criteria, the entire crossing location qualifies for a pedestrian crossing treatment.

5. POTENTIAL PEDESTRIAN TREATMENT ALTERNATIVES

When evaluating a pedestrian crossing location, several treatments can be installed to facilitate the pedestrians' ability to cross the street. The recommended treatments (or no action) are based on whether or not the location meets the warrant criteria. The treatments are described in the sections below in the order in which they should be considered. When a pedestrian treatment is installed at a non-intersection location (i.e., mid-block crosswalk), curbside parking should be prohibited for 100 feet in advance of and 20 feet beyond the crossing treatment.

A. NO ACTION

If the pedestrian crossing location does not meet the warrant criteria, no additional actions to accommodate the pedestrians are required.

B. INSTALL MARKED, SIGNED CROSSWALK

If the pedestrian crossing location does not meet the warrant criteria, a marked and signed crosswalk may be installed. Crosswalks do not provide any physical protection to the pedestrian. However, they do alert drivers to the presence of pedestrians or the likelihood of pedestrian activity, and they encourage pedestrians to cross at locations where drivers expect them. Marked, signed crosswalks establish legal pedestrian crossings at mid-block crossing locations.

A marked, signed crosswalk should be installed at pedestrian crossing locations with the following characteristics:

- 50 or more pedestrian crossings during any hour
- Average daily traffic (ADT) of 5,000 or more vehicles per day
- A minimum distance of 300 feet to the nearest protected pedestrian crossing

A marked, signed crosswalk should not be installed where there is inadequate stopping sight distance, where the speed limit is greater than 40 mph, or where there is an average daily traffic volume in excess of 15,000 vehicles per day. For locations with more than 50 pedestrians per hour, and more than 15,000 vehicles per day traffic volume or a speed limit greater than 40 mph, the pedestrians should be directed to the nearest protected pedestrian crossing. There is an overriding safety concern at locations with more than 50 pedestrians per hour and inadequate stopping sight distance; at these locations, the pedestrian warrant is met and should be evaluated for an appropriate treatment (i.e., neckdowns, median / refuge islands, or a signal).

C. SCHOOL ROUTE PEDESTRIAN TRAFFIC

If peak pedestrian volumes at a pedestrian crossing location consist of children on their way to or from school, consult the City's policy on school routes.

D. INSTALL NECKDOWNS

A neckdown is a narrowing of the street, either at an intersection or as a mid-block location, to reduce the width of the roadway. Neckdowns are usually achieved by moving the curb lines toward the center of the roadway and increasing the area behind the curb. Streets narrowed at the crosswalk reduce the distance over which pedestrians are exposed to vehicular traffic. They provide protection to pedestrians because street crossing distances are shorter and vehicles approach at a predictable location. Neckdowns typically improve visibility between pedestrians and motorists prior to the pedestrian leaving the curb, especially when there are cars parked along the edge of the roadway. Neckdowns may have a negative impact on bicycle travel and may not be appropriate for use on established bike routes.

E. INSTALL MEDIAN / REFUGE ISLAND

Medians are typically raised, semi-protected areas located in the middle of the street between the opposing directions of traffic. Raised medians can add significantly to pedestrian mobility and safety on multi-lane roadways. They enable pedestrians to cross the street in two independent phases and are especially helpful in wide streets with two or more lanes of traffic in each direction. Medians provide some physical protection to pedestrians and increase their visibility to motorists. In addition, medians do not affect arterial traffic flow or increase vehicular delay. A refuge island provides similar benefits at a pedestrian crossing as a median, but it is shorter in length (it does not extend along the length of the roadway).

Medians (or refuge islands) reduce pedestrian delay. They allow pedestrians to cross the roadway in two stages, concentrating on vehicles from one direction at a time. Todd reported on two pedestrian delay studies: Gerlough showed pedestrians took seven times longer to cross a two-way street without a refuge than with one and Smith et al. noted a delay ten times as long. The ability to segment the crossing into two simpler parts reduces pedestrian delay and increases crossing safety.

Installation of a median (or refuge island) increases the number of acceptable gaps when the number of through lanes per direction remains unchanged. Boulder field data showed that roads with a median had over five times as many available gaps as similar roads without medians. A median results in fewer gaps per direction if a through lane is removed, but the addition of a median may still provide more total acceptable gaps for each direction than the total acceptable gaps that are available with an existing two-way, uninterrupted crossing of the roadway.

When evaluating median installation at a pedestrian crossing, the following geometric issues should be considered:

- A median refuge for pedestrians should be at least six feet wide for comfortable storage of the 15th percentile pedestrian. A median of this width will allow over two feet on each side for splash protection; it will store a group of pedestrians; and it will accommodate the storage of a bicycle without it overhanging into the traffic lanes.

- A minimum roadway width of thirty to thirty-four feet is required to provide a six foot median refuge with two twelve to fourteen foot through traffic lanes.

- The design of the median crossing should conform to the handicapped requirements of the ADA (Americans with Disabilities Act).

- The crosswalk through the median should not be humped, raised or crowned any more than is necessary for drainage.

Medians enable safe pedestrian crossings while maintaining traffic efficiency. If a median cannot be constructed, consideration should be given to localized widening to provide for a pedestrian refuge island at the location of the pedestrian crossing. Pedestrian refuge islands should be at least six feet wide and fifty feet long to adequately shelter pedestrians.

F. INSTALL PEDESTRIAN SIGNAL

If the pedestrian crossing warrant criteria are met and no other type of treatment will adequately accommodate the pedestrians, a traffic signal should be considered to provide for safe pedestrian crossings. Timing of the pedestrian crossing signal is important. According to the ITE Handbook, a threshold delay exists beyond which pedestrians will ignore the signal and accept natural gaps in the traffic to cross the street. Signals which require pedestrians to wait longer than they are willing are likely to create unnecessary vehicular delays. When a pedestrian activates the push button and then accepts an available gap before receiving the green signal, vehicular traffic is stopped unnecessarily when the pedestrian crossing is permitted by the signal. For these reasons, the issue of delay should be addressed on a case by case basis at each pedestrian crossing location being evaluated. If installation of a signal at the proposed location is expected to increase pedestrian delay over the existing conditions, then a lesser option (such as neckdowns or a median/refuge island) should be considered. This situation may occur at a location that requires signal coordination. An uncoordinated pedestrian demand-activated signal would not be an appropriate device along a corridor with coordinated signal timing due to its potentially extreme negative impact on traffic flow in the corridor. A pedestrian signal should therefore be coordinated with the corridor timing plan at such a location to maximize the operational efficiency for pedestrians, bicyclists and motorized vehicles. This is consistent with the City's policy to install traffic signals where they will provide the greatest benefit to the community.

A pedestrian signal might incur more pedestrian delay if the signal is located within a corridor with a 120 second cycle length. At such locations, the average pedestrian delay will be about 60 seconds. In some cases, this delay may be greater than the existing condition or the neckdown or median/refuge island alternatives. As such, the preferred alternative would be to install the treatment that minimizes pedestrian delay. However, failure to install protected pedestrian crossings only based on delay alone will not help encourage some pedestrians who would rather use their cars than cross without a pedestrian signal. Therefore, the decision should be based on a careful consideration of the conditions at each site.

Traffic signals whose installation are based on pedestrian crossing warrants could be installed at intersection or mid-block locations, depending on the specifics of the given crossing location. Mid-block pedestrian signals are placed at non-intersection locations which correspond to specific pedestrian crossing locations with sufficient demand and are not within reasonable distance of other safe crossing facilities. A traffic signal may be installed at an intersection where pedestrian crossing warrants are met, even if vehicular volume does not meet signalization warrants. If a signal is warranted at an existing intersection then it will be coordinated with the existing signal system.

Pedestrian signals installed at mid-block locations could be installed as pedestrian crossovers. The signal heads for pedestrian crossovers have the standard red-yellow-green ball configuration. The signal rests in the green phase for the vehicular traffic while a "don't walk" symbol is displayed for the pedestrian. The pedestrian uses the push button to let the system know that he or she wants to cross the street. The signal turns yellow then red for the vehicular traffic. The signal remains solid red for five to seven seconds, during which time the pedestrian signal displays the "walk" symbol. After the minimum solid red phase is over, the signal goes to flashing red for the vehicular traffic and flashing "don't walk" for the pedestrian. The flashing red vehicular signal requires vehicles to stop at the crosswalk. But if the pedestrian has cleared the crosswalk, the vehicle may proceed with no additional delay. The length of the flashing red phase is dependent upon the pedestrian crossing distance. After the flashing red phase is over, the vehicular signal reverts to the solid green display. The pedestrian signal reverts to a solid "don't walk" symbol a few seconds prior to the display of the green vehicle signal. It is recommended that pedestrian crossovers be installed initially in one or more test locations to verify their effectiveness as an alternative to conventional pedestrian crossing signalization.

Pedestrian crossover signals provide for pedestrian safety while minimizing vehicular delay. Both are important considerations in the City of Boulder with the emphasis on alternate mode travel and the substantial roadway traffic volumes. Pedestrian safety is not compromised with the use of pedestrian crossover signals. Vehicles are required to stop and look for pedestrians and it is likely that driver disregard of pedestrian crossings is minimized as a result of the reduced vehicular delay.

Pedestrian signals installed at mid-block locations have less negative impact on vehicular traffic flow efficiency than do pedestrian signals installed at intersection locations, due to side street vehicle actuation at the intersection locations. This negative effect can be minimized by coordinating the signals within the surrounding signal system.

Signals installed under this warrant should be actuated with push buttons for pedestrians wanting to cross the major street. In addition, the signals should be equipped with pedestrian indications conforming to requirements set forth in the MUTCD.

If a pedestrian signal cannot or should not be installed due to overriding traffic engineering considerations, such as geometric limitations, the lesser options (neckdowns or median/refuge island) should be evaluated. If none of these alternatives are appropriate and the crossing is a high priority in the pedestrian system, a grade-separated crossing (underpass or overpass) should be considered.

If a pedestrian signal is not a viable option and neckdowns or a median/refuge island will significantly improve the pedestrian crossing opportunity and safety, then such improvements should be considered even if the number of acceptable gaps are not increased to the 120 gaps per hour recommended in this warrant criteria. A reasonable standard to use when evaluating a lesser pedestrian crossing treatment instead of a signal is the MUTCD standard of 60 acceptable gaps per hour (representing an average pedestrian delay of 60 seconds). If neckdowns or a median/refuge island provide at least 60 acceptable gaps per hour at a location where a signal is not a practical alternative, then their installation would be appropriate.

An example of the appropriate application of a lesser alternative is the Valmont Road pedestrian crossing at 34th Street. A signal at this location was not possible due to roadway geometric constraints. A grade-separated crossing was not a viable alternative due to the geometry, right-of-way constraints, anticipated pedestrian usage and cost. However, installation of a raised refuge island in the middle of the five-lane roadway increased the available acceptable gaps from two gaps per hour to eighty gaps per hour by allowing pedestrians to cross the street in two phases. Although it provides less than 120 gaps per hour, installation of the refuge island greatly improved pedestrian crossing opportunity and safety.

6. EVALUATING A PEDESTRIAN CROSSING LOCATION

The following steps should be used to evaluate an unprotected pedestrian crossing location for compliance with the Boulder warrant criteria. The warrant criteria does not apply to school crossings or protected crossings where a traffic control device (i.e., a stop sign) stops the flow of traffic and gives pedestrian the right of way. The pedestrian crossing warrant flow chart (illustrated in Figure 5) clarifies the process and it should be used in conjunction with this list.

(1) Identify the pedestrian crossing location. Is it a primary pedestrian corridor with overriding need (multi-use path, bike corridor, transit access)? (If yes, go to Step 4.) It is important to check pedestrian volumes during hours of peak vehicle traffic (morning, noon and evening peaks) as well as expected hours of peak pedestrian volume.

(2) Determine the pedestrian crossing volume for the peak hour and for the peak four hours. Are there more than 100 pedestrians during the peak hour, or more than 50 pedestrians per hour during the peak four hours? If so, go to Step 3. If not, no action is required but installation of a marked, signed crosswalk may be warranted (go to Step 9 for the crosswalk criteria). Each young, elderly or handicapped pedestrians should be counted as two pedestrians for the pedestrian volume calculation. Bicycles should be included in the volume measurement if there are inadequate gaps to accommodate bike crossings.

(3) Measure the distance to the nearest protected pedestrian crossing (i.e., traffic signal or grade-separated crossing). Is it greater than 300 feet? If it is, go to Step 4. If it is not, no action is required. However, installation of signage directing pedestrians to the protected crossing may be considered.

(4) Identify the roadway geometry at the pedestrian crossing location (crossing distance, lane configuration, etc.).

(5) Identify the type of pedestrians (standard, elderly/handicapped/young) and select the appropriate walking speed for adequate gap calculations (4.0 feet per second for standard, 3.5 feet second for more than twenty percent elderly/handicapped/young).

(6) Calculate the adequate gap (amount of time) required for a pedestrian to cross the street. (Use the equation in Section 3E or Table 3.) If the crossing has a fair amount of bicycle traffic, calculate the adequate gap required for bicyclists to cross the street.

(7) Determine the major street average daily traffic volume at the pedestrian crossing location.

(8) Determine the number of adequate gaps available during the pedestrian peak hour. Is [ADT]*[Crossing Distance (ft)] / [1,000] greater than 200? If so, then a gap study should be conducted to determine the number of adequate available gaps. If there are more than 120 acceptable gaps per hour during the peak hour(s), no action is required but installation of a marked, signed crosswalk may be warranted (go to Step 9 for the crosswalk criteria). If there are less than 120 acceptable gaps per hour, then the pedestrian crossing location meets the warrant criteria and an appropriate pedestrian treatment may be installed (go to Step 10). If

a bicycle gap calculation is appropriate and if there are less than 120 acceptable gaps per hour for bikes, then the pedestrian volume should be adjusted to include the bicycle volume (re... to Step 2).

(9) If the pedestrian crossing does not meet one or more of the warrant criteria, it should be evaluated for a signed, marked crosswalk. A crosswalk should be installed at pedestrian crossing locations which meet the following minimum requirements:

- 50 or more pedestrian crossings during any hour
- Average daily traffic (ADT) of 5,000 or more vehicles per day
- A minimum distance of 300 feet to the nearest protected pedestrian crossing

(10) If the pedestrian crossing meets the warrant criteria, decide which pedestrian treatment is most appropriate for the crossing location.

(a) Evaluate neckdown installation:

- Is there adequate roadway width for installation?
- What is the new crossing distance?
- What is the adequate acceptable gap required for the new crossing distance?
- Will there be more than 120 adequate acceptable gaps per hour if a neckdown is installed?
- Is there an established bike route at the pedestrian crossing location?

If the reduced crossing distance increases the number of available acceptable gaps to more than 120 gaps per hour and if the geometrics allow it, then a neckdown may be installed. The neckdown should be supplemented with a marked, signed crosswalk. If the crossing traverses an established bike route, a neckdown may not be appropriate due to the potential negative impact of neckdowns on bicycles.

(b) Evaluate median (or refuge island) installation:

- Is there adequate roadway width for installation?
- What are the new crossing distances?
- What are the adequate acceptable gaps required for the new crossing distances?
- Will there be more than 120 adequate acceptable gaps per hour for crossing each direction of traffic if a median (or refuge island) is installed?

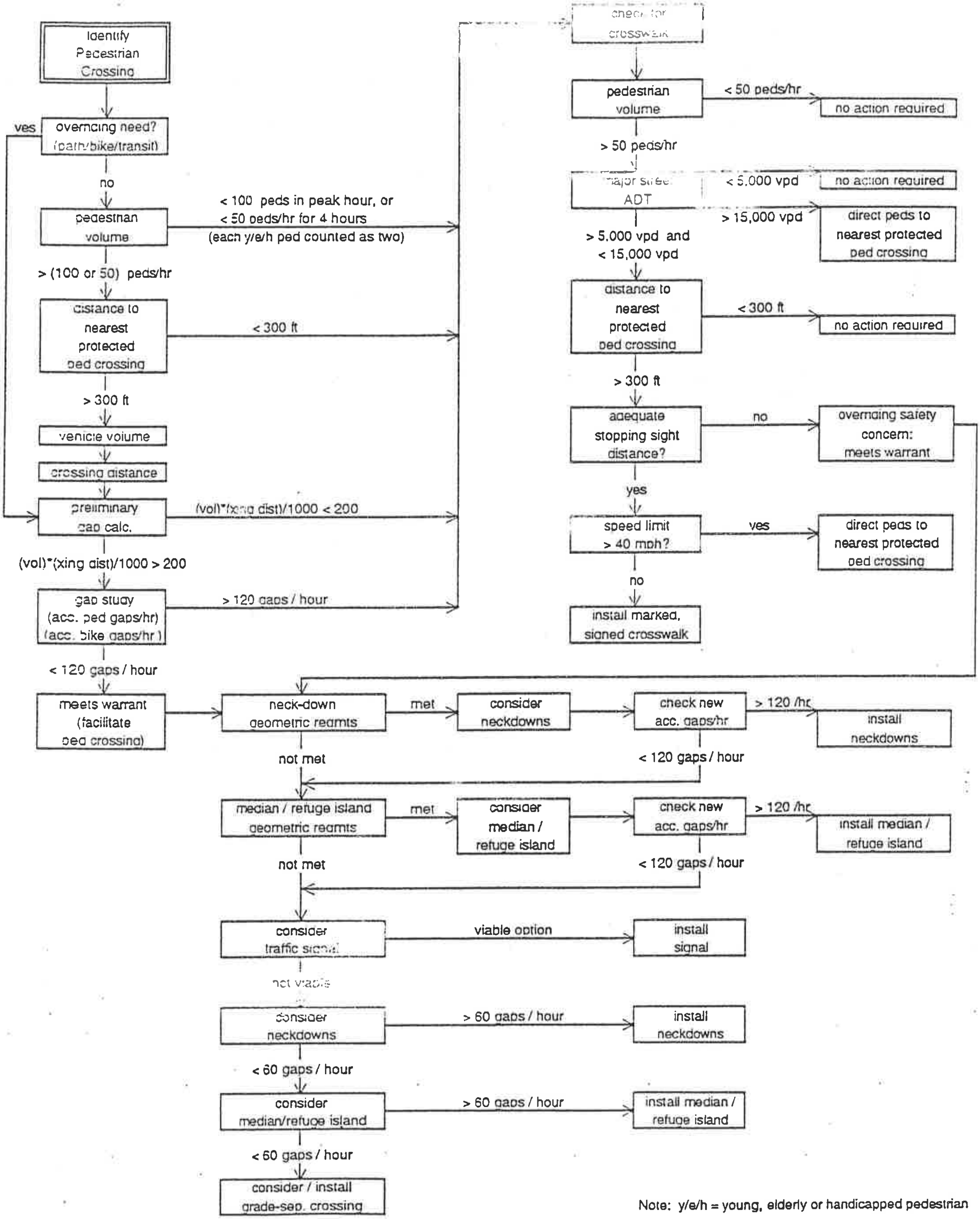
If the reduced crossing distances increase the number of available acceptable gaps to more than 120 gaps per hour for each crossing direction and if the geometrics allow it, then a median or pedestrian refuge island may be installed. The median or refuge island should be supplemented with a signed, marked crosswalk.

(c) If the pedestrian crossing warrant criteria are met and no other type of treatment will adequately accommodate the pedestrians, a traffic signal should be considered to provide for safe pedestrian crossings. Installation of a pedestrian signal should be the last at-grade treatment considered for a pedestrian crossing location due to its cost, the increase in vehicular delay, and the possible increase in pedestrian delay over the other types of treatments previously discussed.

If a traffic signal is not a viable alternative, re-evaluate the neckdown and median/refuge island alternatives. If one of these lesser treatments provides at lease 60 acceptable gaps per hour, its installation would be appropriate. If not, installation of a grade-separated crossing should be considered.

(11) In all cases when applying these warrant criteria, City staff should use engineering judgement to insure that the crossing treatment meets the needs of the specific location under consideration and that the improvements are consistent with the transportation system in the area. For example, if a location warrants the installation of a median refuge, but happens to be at the same location where an improved underpass is planned as part of the Greenways Program, the need for a median refuge should be reevaluated, and possibly waived, if the underpass can serve the need while also benefitting storm drainage and other riparian issues.

Figure 5 Pedestrian Crossing Warrant Flow Chart



Note: y/e/h = young, elderly or handicapped pedestrian

7. CITY-WIDE IMPACT OF PEDESTRIAN CROSSING WARRANTS

Implementation of the Boulder pedestrian crossing warrants will have a city-wide effect on pedestrian travel. It is expected that appropriate pedestrian treatments are likely to be required at identified pedestrian corridor locations, such as 20th Street at Canyon Boulevard and 15th Street at Iris Avenue. Anticipated pedestrian crossing treatments may be required at the identified locations listed below:

- Possible neckdown locations:

  Arapahoe Avenue near the library
  Spruce Street near the Spruce Street Pool
  Violet and Yarmouth with construction of the village center in north Boulder

- Possible median refuge locations:

  Canyon Boulevard at 20th Street
  Iris Avenue at 15th Street (13th Street bicycle corridor)
  Pearl Street between 28th and 30th Streets

- Possible pedestrian signal locations:

  Canyon Boulevard at 11th Street
  9th Street at Walnut Street
  Arapahoe Avenue at 19th Street
  Folsom Avenue at Walnut Street

- Possible pedestrian crossover locations:

  Table Mesa near King Soopers (modification of existing signal)
  Arapahoe Avenue near the Naropa Institute (modification of existing signal)
  Canyon east of 19th Street (near the park)

The pedestrian crossing treatment warrants developed in this document are intended to provide a consistent procedure for considering the need for crossing improvements and the type of crossing treatments appropriate where needed on a case-by-case basis in the City of Boulder. Implementation of crossing treatments will require funds that could potentially have been spent on other transportation system improvements and, therefore, must be considered carefully in the funding allocation process. Staff should coordinate the installation of pedestrian crossing treatments with other projects and programs (such as the Greenways Program) or ongoing construction projects to insure that the greatest improvement for pedestrians and bicyclists can be achieved within the limits of available funding.

APPENDIX 1

DATA COLLECTION AND ANALYSIS

DATA COLLECTION AND ANALYSIS

In order to develop the pedestrian crossing warrant criteria addressed in the body of this report, extensive research of available technical literature was conducted and three pedestrian crossing locations within the City of Boulder were evaluated. The crossing locations were Canyon Boulevard / 11th Street, 9th Street / Walnut Street and Arapahoe Avenue / 19th Street; all three crossings experienced relatively high levels of pedestrian traffic. In addition, pedestrian behavior at the existing signalized crossing on the Pearl Street Mall at Broadway was observed. Each location was videotaped for one hour and a computer program was used to measure pedestrian crossing behavior (initial and intermediate delay, crossing time for each side of the street, gaps accepted and gaps rejected). The entire data collection and reduction process was time consuming but necessary to evaluate the desired pedestrian behavior patterns.

1. METHODOLOGY

Four locations within Boulder with relatively substantial pedestrian usage were selected and evaluated for this study. Three locations were unsignalized, the fourth was signalized. Each crossing location was videotaped and the following information was recorded:

- Traffic volume
- Pedestrian volume
- Gaps between vehicles
- Pedestrian delay
- Gaps accepted by pedestrians
- Gaps rejected by pedestrians
- Pedestrian crossing time

The above data was manipulated to determine the following information:

- Pedestrian walking speed: was calculated by dividing crossing distance by crossing time

- Gaps accepted by pedestrians: were determined for pedestrians who were delayed prior to entering the crossing. The accepted gap was the amount of time from when the rear of the vehicle passed in front of the pedestrian until the front of the next vehicle passed the same spot.

- Gaps rejected by pedestrians: were determined for pedestrians who were delayed prior to entering the crossing. All gaps which were not accepted by a waiting pedestrian were measured.

- Vehicle gaps: were measured between all vehicles in the traffic stream for the duration of the study.

- Acceptable pedestrian delay: was calculated as described in Section 4e, below.

Statistical analysis was completed for the above measurements to determine mean, median, 15th percentile, 85th percentile, and frequency distribution, as applicable. This information was then used to help create the Boulder pedestrian crossing warrant criteria.

2. LOCATION DESCRIPTIONS AND OBSERVATIONS

The geometry of each pedestrian crossing location affected the pedestrians' behavior and ability to cross the street. The following paragraphs describe the unique characteristics at each location.

A. CANYON BOULEVARD / 11th STREET

Canyon Boulevard is a principal east-west arterial located on the south side of downtown Boulder. It is a five-lane roadway with a four foot raised median (two through lanes in each direction plus left turn bays). 11th Street is a north-south local access roadway on the west side of downtown Boulder; to the north, it is a two-lane roadway with parking on both sides of the street. 11th Street meets Canyon Boulevard in a "T" intersection at its south end. The Boulder Public Library and parking lot is located southwest of the intersection, City buildings are on the southeast side of the intersection, and the Boulder Creek Path is south of the intersection. There are office buildings and restaurants on the north side of the intersection, and 11th Street connects to the west end of the Pearl Street Mall which is two blocks north of Canyon Boulevard. These facilities, together with downtown employment and retail, are primary contributors to pedestrian traffic in the area.

There is a marked crosswalk on the east side of the intersection and an unmarked crossing on the west side to accommodate pedestrian traffic. There is plenty of visibility to the east and west of the intersection. The nearest signalized pedestrian crossings are 680 feet to the west (at 9th Street) and 310 feet to the east (at Broadway). There are approximately 21,000 vehicles per day on Canyon Boulevard and 2,000 vehicles per day on 11th Street. Figure 6 illustrates the intersection and the pedestrian crossings.

The pedestrian arrivals during the noon peak were fairly well dispersed, with pedestrians crossing primarily by themselves or in small groups. The vast majority (approximately 90 percent) of the pedestrians who crossed Canyon at 11th stopped in the middle or "shot the gap" (used directional gaps separately) in order to cross both sides of the street. Pedestrians who had to wait in the middle for a gap on the other side of the street used the median and left turn bay area for protection. Pedestrians who shot the gap crossed the street while there was traffic in one or more of the through lanes that they were not currently walking in, enabling them to take advantage of smaller gaps in the traffic. The "yield to pedestrian" signs seem to have a positive effect. Some vehicles slowed or stopped for pedestrians as they were attempting to cross the street. Most were vehicles waiting to turn left from Canyon to 11th or into the parking lot.

B. 9th STREET / WALNUT STREET

9th Street is a north-south minor arterial at its intersection with Walnut street in the western downtown area. It is a three-lane roadway with bike lanes and parking on both sides of the street (one through lane in each direction plus left turn bays). Walnut Street is an east-west local access roadway and part of the downtown circulator loop between 11th Street and 15th Street. It is a two-lane roadway with parking on both sides of the street. The intersection of Walnut Street and 9th Street is a standard four-legged intersection with crosswalks on all approaches. The office buildings, restaurants, commercial businesses and parking lot in the vicinity of the intersection are primary contributors to pedestrian traffic in the area.

For pedestrians waiting on the sidewalk, visibility at the intersection is somewhat obscured by the parked cars. Once past the parked cars, there is plenty of visibility to the south. Visibility to the north is less substantial due to the roadway configuration. The nearest signalized pedestrian crossings are 320 feet to the north at Pearl Street, and 305 feet to the south at Canyon. There are approximately 18,000 vehicles per day on 9th Street and 3,000 vehicles per day on Walnut Street. An illustration of the intersection and the pedestrian crossings is shown in Figure 7.

Pedestrians illustrated mixed behavior regarding the use of the left turn bay as a break point for crossing the street. Approximately three percent of the pedestrians stopped in the middle to wait for a gap in the opposing traffic stream. However, some of the pedestrians stopped because they misjudged the southbound traffic. The southbound traffic was somewhat deceiving; the downhill approach made the gaps in traffic appear larger than they were and the gaps seemed to close faster than the pedestrians anticipated. Fortunately, vehicles were generally responsive to pedestrians, stopping frequently to allow pedestrians to finish crossing the street.

C. ARAPAHOE AVENUE / 19th STREET

Arapahoe Avenue is a east-west minor arterial at its intersection with 19th Street north of the University of Colorado and campus and east of Boulder High School. It is a three lane roadway (one through lane in each direction plus left turn bays) with no parking. 19th Street is a north-south local access roadway and a popular bike/pedestrian route to and from the university and high school campuses. It is a two lane roadway with parking. Parking is permitted on the east side of 19th Street north of Arapahoe and on both sides of the street south of Arapahoe.

The intersection of Arapahoe Avenue and 19th Street currently has no pedestrian treatments. The nearest signalized pedestrian crossings are 590 feet to the west (at 17th Street) and 870 feet to the east (at the Naropa Institute) There are approximately 33,000 vehicles per day on Arapahoe Avenue and 1000 vehicles per day on 19th Street. An illustration of the intersection and the pedestrian crossings is shown in Figure 8.

Unlike the other pedestrian crossings, data was collected during the morning peak at this location. Vehicles seemed to be traveling somewhat faster (commuter-type traffic) and the pedestrian population was composed primarily of high school and college students. Generally, the pedestrians were not afraid to stop in the middle of the street to wait for a gap, despite the minimal protection offered there. The owner of a nearby grocery store approached the individual videotaping the area and stated that he thought the Naropa Institute pedestrian signal should be relocated to the 19th Street crossing due to the safety problems and the difference in pedestrian usage at the two locations.

D. BROADWAY / PEARL STREET MALL

The Pearl Street Mall is a former roadway that has been converted into a pedestrian mall. There is a traffic signal at its intersection with Broadway to control the pedestrian and vehicular movements to allow safe and efficient passage by all intersection users. Broadway is a principal north-south arterial; it is a four-lane roadway with two through lanes in each direction.

There is a wide, brick crosswalk across Broadway to indicate the appropriate pedestrian crossing location. There are approximately 25,000 vehicles per day on Broadway. At noon, when the data was collected, this signal has a 72 second cycle length with 12 seconds of "green" time for the pedestrians. This means there is a maximum delay of 60 seconds for pedestrians waiting to cross the street. In general, pedestrians were willing to wait for the signal to cross the street. There were a few pedestrians who crossed against the signal when there was an available gap in traffic. An illustration of the Pearl Street Mall crossing is shown in Figure 9.

Figure 6: Pedestrian Crossing Geometry - Canyon Boulevard at 11th Street

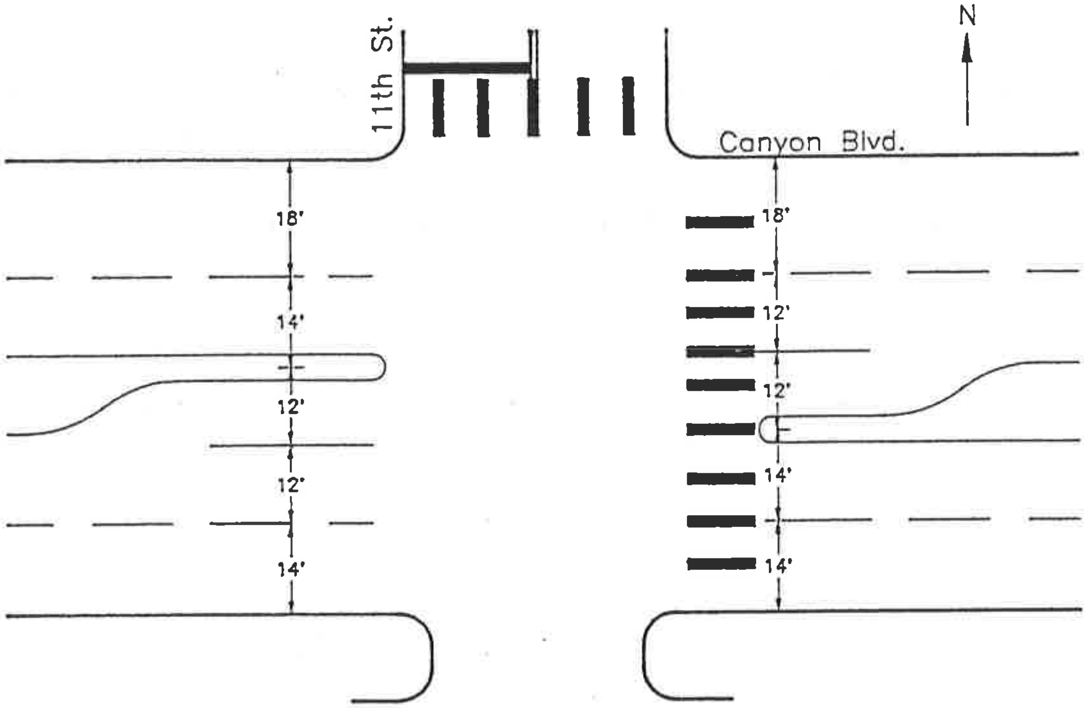


Figure 7: Pedestrian Crossing Geometry - 9th Street at Walnut Street

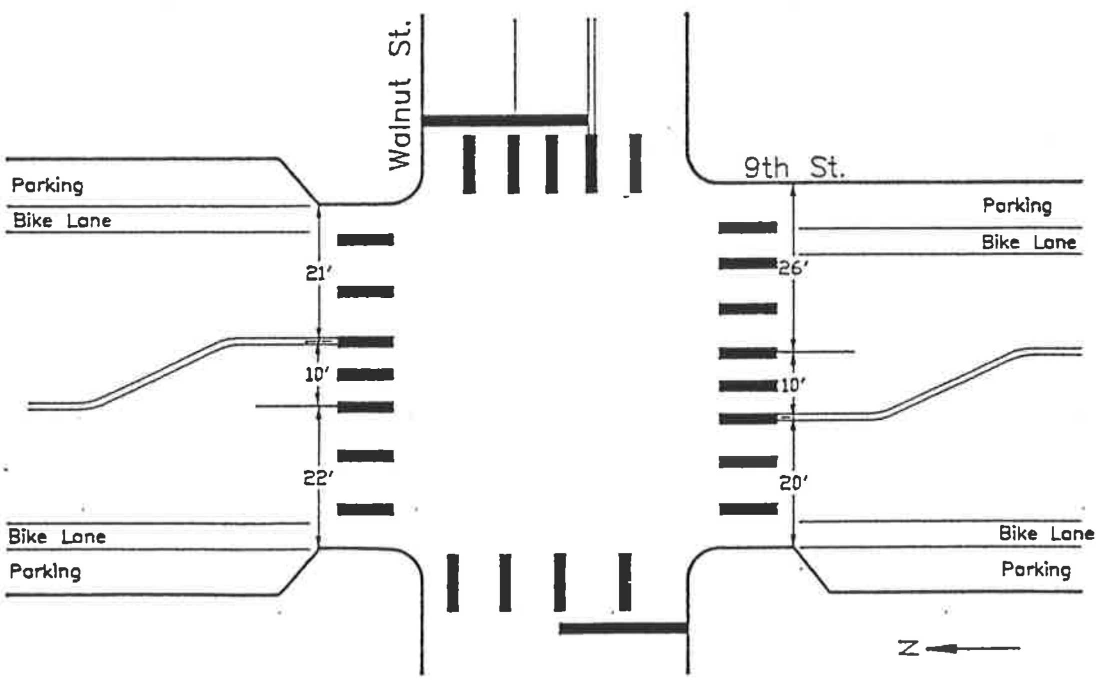


Figure 8: Pedestrian Crossing Geometry - Arapahoe Avenue at 19th Street

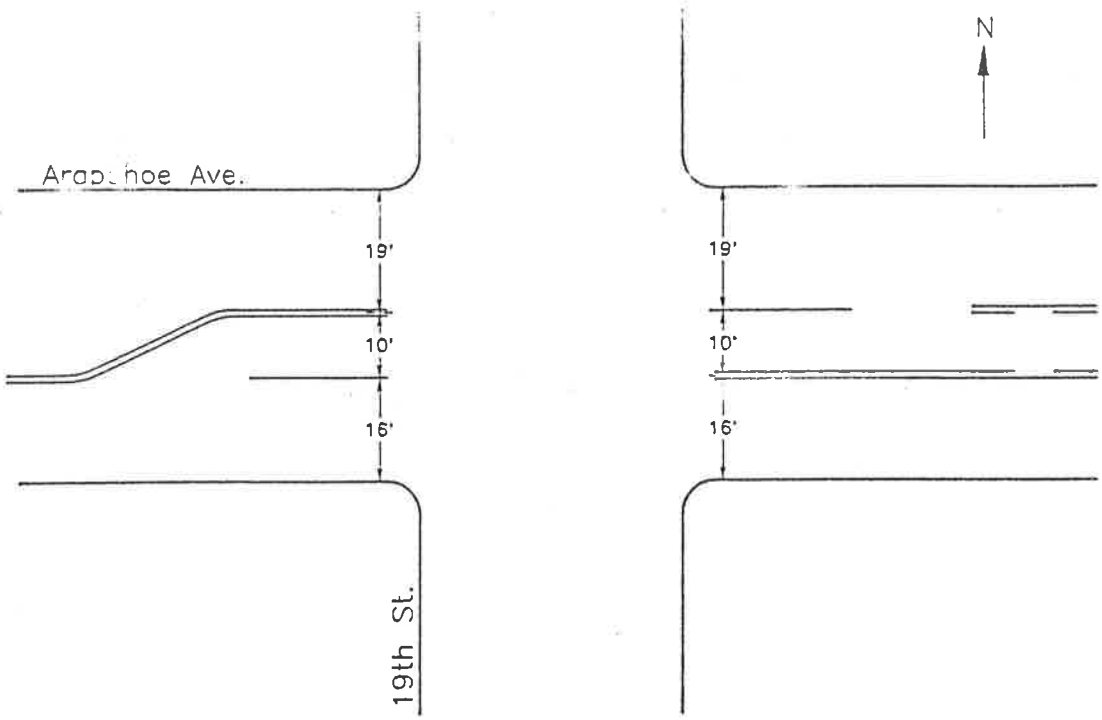
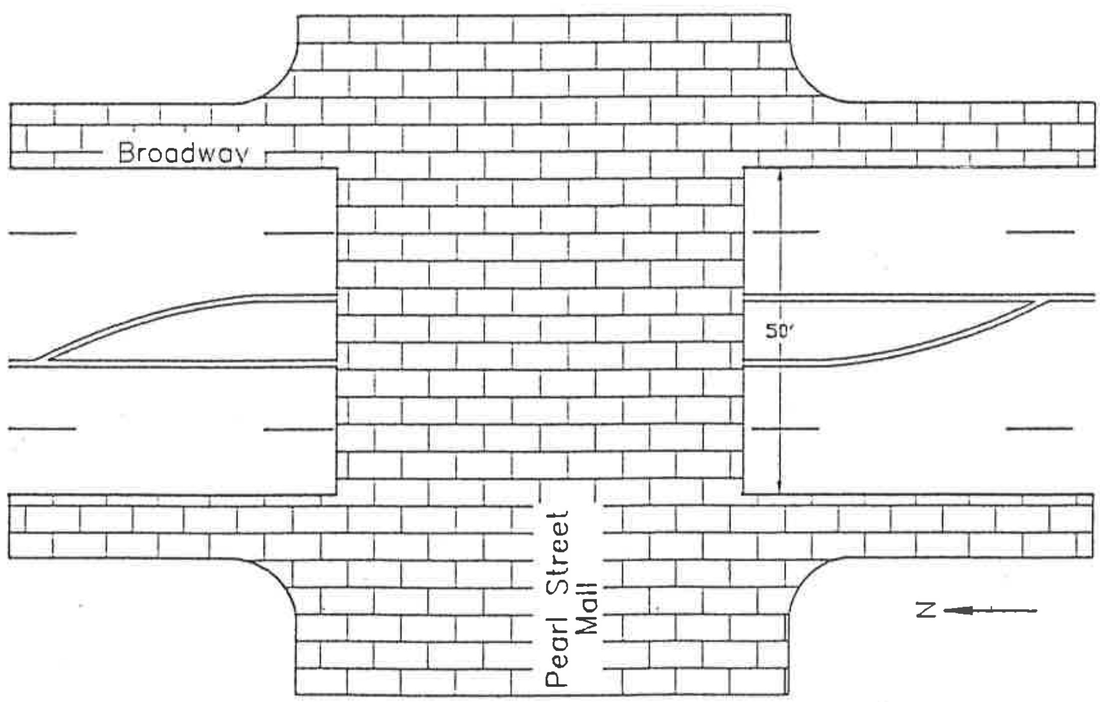


Figure 9: Pedestrian Crossing Geometry - Broadway at the Pearl Street Mall



E. SUMMARY OF CROSSING LOCATIONS

Based on the crossing locations observed, a significant portion of the pedestrian population is willing to use a median/turn lane as a pedestrian refuge while crossing a busy street. However, the 15th percentile pedestrian (typically an elderly pedestrian or a parent with a child) was much less willing to take that risk. Note that the pedestrian data that was collected at each location was for pedestrians who were willing to cross the street under the given conditions. With greater pedestrian protection, more pedestrians are likely to use a particular crossing.

There were more longer gaps at the crossing locations closer to an existing traffic signal than others. When vehicles start up after being stopped at a signal, they are closer together. As they proceed down the road they tend to spread out. This results in more longer gaps between vehicle platoons and shorter gaps within the platoons at locations near a signal and more evenly spaced medium sized gaps between vehicles at a greater distance from a signal.

3. DATA COLLECTION

Pedestrian movements were videotaped at each location during times of heavy pedestrian usage; data was collected during the noon peak at the three downtown locations (Canyon / 11th Street, 9th Street / Walnut, and Broadway / Pearl). Data was collected during the morning school peak at the Arapahoe / 19th Street intersection. The following information was measured from the videotapes: traffic volume, pedestrian volume, gaps between vehicles, pedestrian delay, vehicle gaps accepted and rejected by pedestrians, and pedestrian crossing time. This data was used to determine pedestrian walking speed, distribution of accepted and rejected gaps, distribution of vehicle gaps, and acceptable pedestrian delay.

In addition to the data collected at the pedestrian crossing locations, vehicle volume and gap data for Balsam Avenue / 13th Street and Valmont Road / 34th Street was included in the study. (This data was available from previous research conducted for the City.)

4. DATA ANALYSIS

A. PEDESTRIAN WALKING SPEEDS

Table 4: 15th Percentile Pedestrian Walking Speeds

Location	Pedestrian Crossing Treatment	Pedestrian Volume (avg + e/h)	Avg Adult Ped Speed (ft/sec)	Elderly/Handicap Ped Speed (ft/sec)
Canyon / 11th	crosswalk, small median	151 + 0	4.2	--
9th / Walnut	crosswalk	105 + 2	4.5	3.9
Arapahoe / 19th	none	58 + 0	4.6	--
Broadway / Pearl	signal	90 + 36	4.9	3.9
15th % Ped Speed	--	404 + 38	4.0	3.5

Pedestrian walking speeds were calculated at each pedestrian crossing location by dividing the crossing distance by the crossing time (excluding any delay incurred in the middle of the street). An [illegible] pedestrian speed for standard and elderly / handicapped pedestrians was then determined. Analysis of the data resulted in the average pedestrian walking speeds as shown in Table 4.

B. DISTRIBUTION OF GAPS ACCEPTED BY PEDESTRIANS

The median and 85th percentile gaps accepted by pedestrians at each location are shown in Table 5. Figures 10 through 12 illustrate the distribution of gap acceptance at each crossing location. Since many pedestrians crossed the streets in two phases (stopping in the middle to wait for an acceptable gap), the gaps are analyzed separately for each direction of traffic.

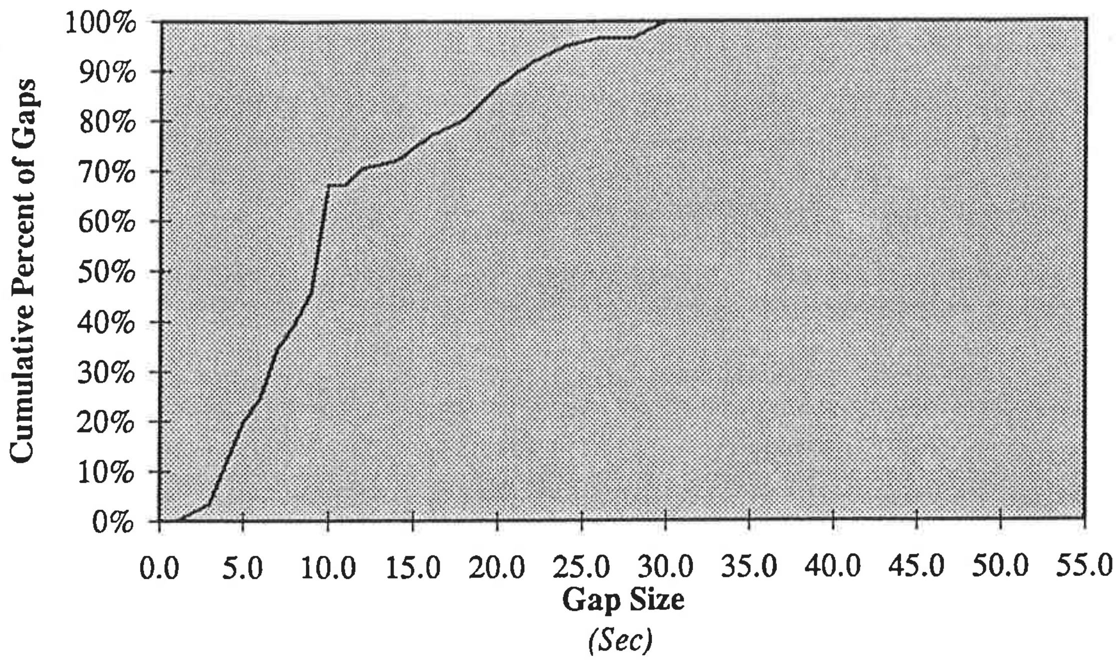
Note: The gap acceptance graphs may be skewed by a small number of "timid" pedestrians. The slope of the line is a relative indicator of the size of the pedestrian population at a given gap size. The flatter the slope, the smaller the population size.

Table 5: Pedestrian Gap Acceptance

Crossing Location	Distance to Nearest Signal	Crossing Distance		Median Accepted Gap (sec)	85th Percentile Accepted Gap (sec)
Canyon / 11th		East	West		
Cross EB Traffic	680 ft	28'	28'	9.3	19.4
Cross WB Traffic	310 ft	42'	32'	9.3	13.3
9th / Walnut		North	South		
Cross NB Traffic	305 ft	21'	36'	7.7	14.0
Cross SB Traffic	320 ft	32'	20'	6.7	15.3
Arapahoe / 19th		East	West		
Cross EB Traffic	590 ft	16'	26'	7.0	8.5
Cross WB Traffic	870 ft	29'	19'	17.5	40.8

Figure 10: Gap Acceptance Distribution - Canyon Boulevard at 11th Street

Crossing Eastbound Traffic at 11th and Canyon



Crossing Westbound Traffic at 11th and Canyon

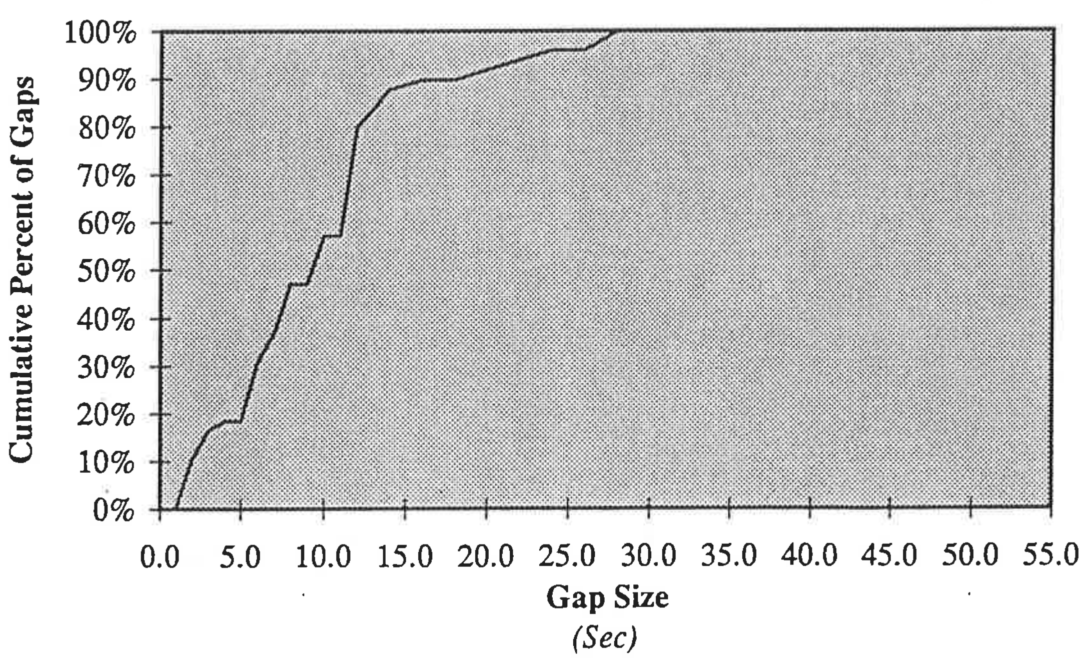
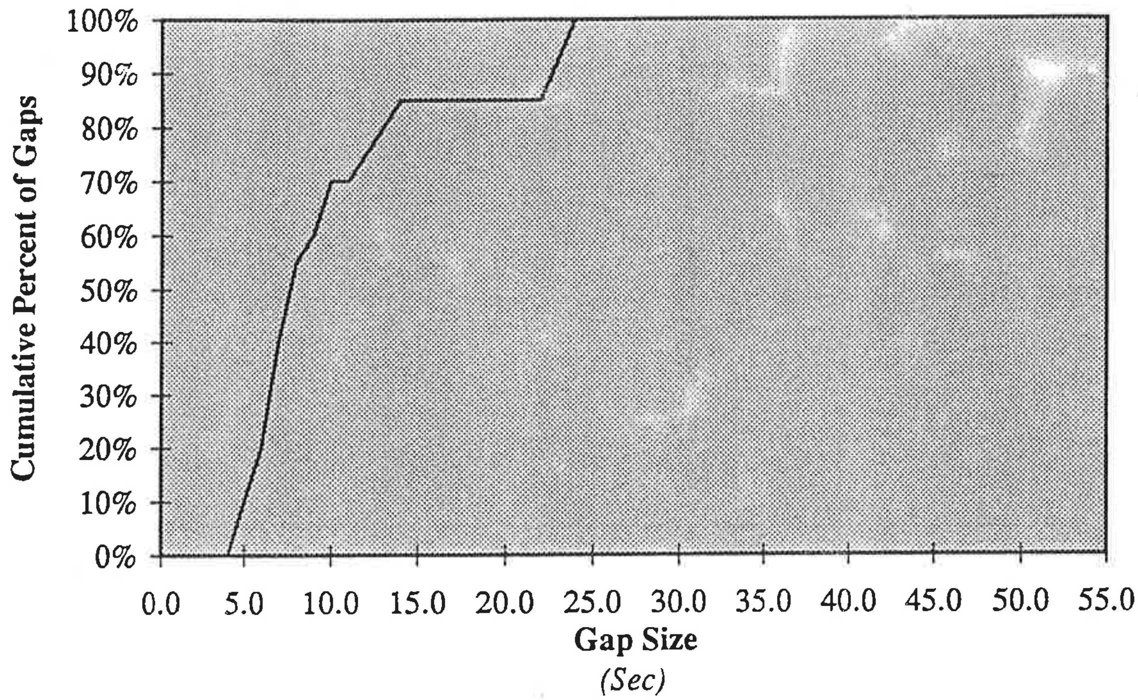


Figure 11: Gap Acceptance Distribution - 9th Street at Walnut Street

Crossing Northbound Traffic at 9th and Walnut



Crossing Southbound Traffic at 9th and Walnut

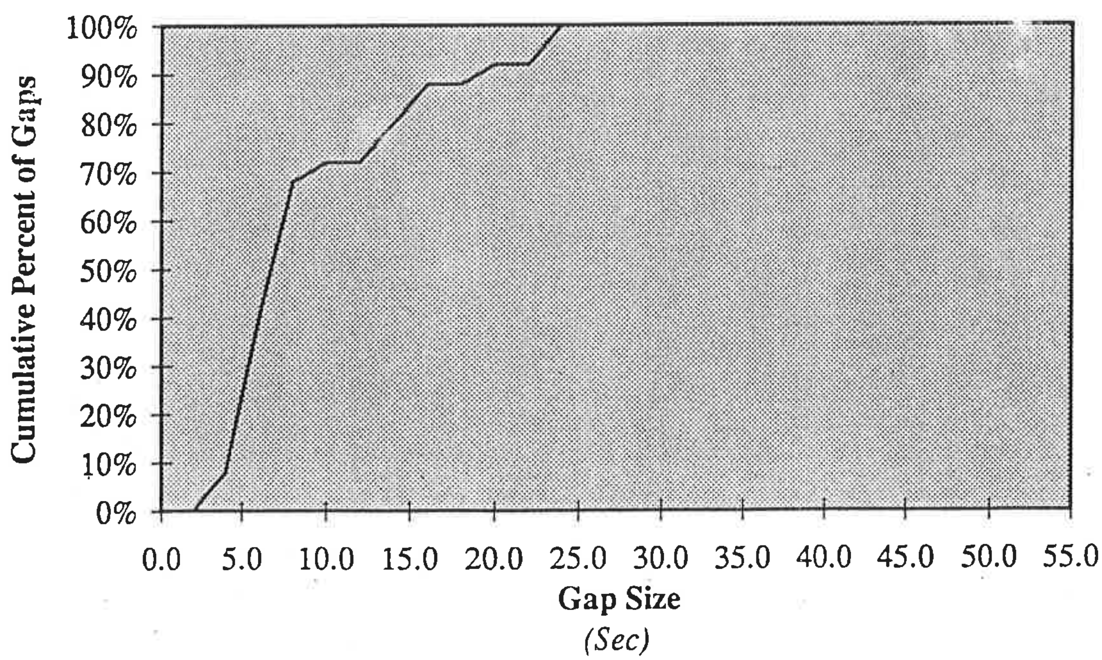
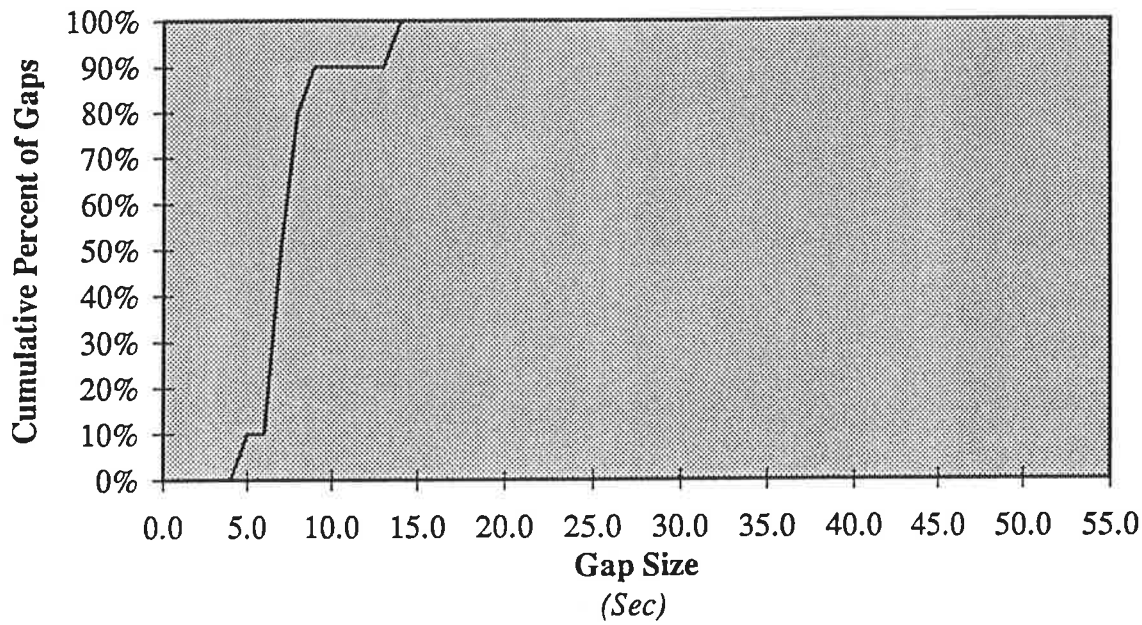
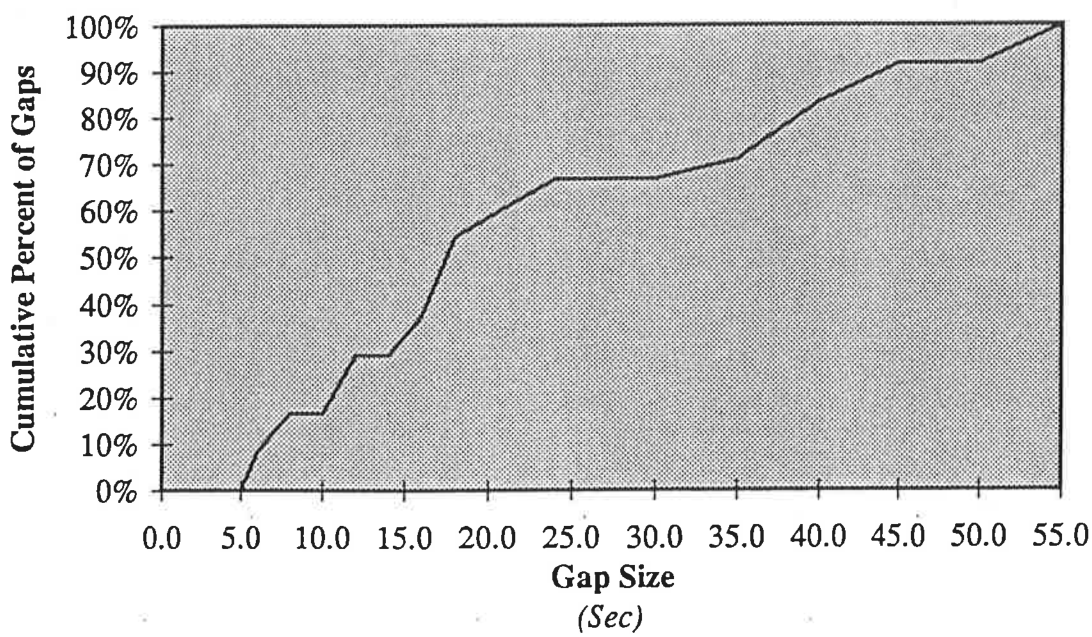


Figure 12: Gap Acceptance Distribution - Arapahoe Avenue at 19th Street

Crossing Eastbound Traffic at 19th and Arapahoe



Crossing Westbound Traffic at 19th and Arapahoe



C. DISTRIBUTION OF GAPS REJECTED BY PEDESTRIANS

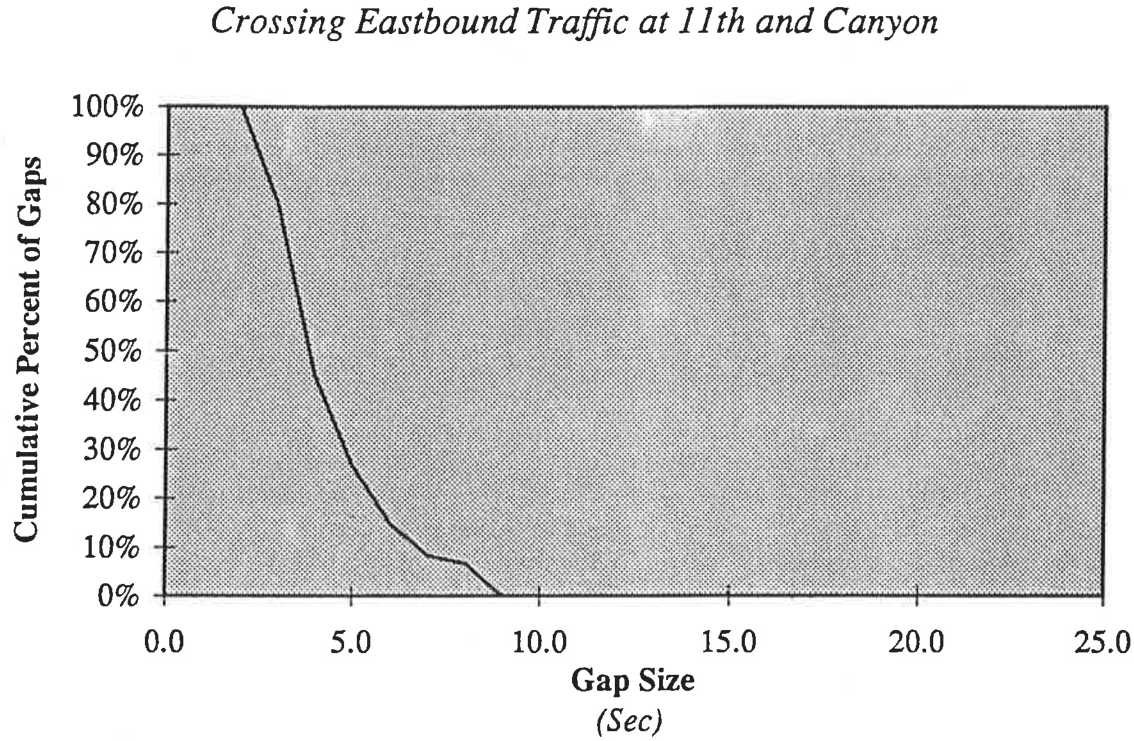
The median and 85th percentile gaps rejected by pedestrians at each location are shown in Table 6. Figures 13 through 15 illustrate the distribution of gap rejection at each crossing location. Since many pedestrians crossed the streets in two phases (stopping in the middle to wait for a gap to accommodate them), the gaps are analyzed separately for each direction of traffic.

Note: The gap rejection graphs may be skewed by a small number of "timid" pedestrians. The slope of the line is a relative indicator of the size of the pedestrian population at a given gap size. The flatter the slope, the smaller the population size.

Table 6: Pedestrian Gap Rejection

Crossing Location	Distance to Nearest Signal	Crossing Distance		Median Rejected Gap (sec)	85th Percentile Rejected Gap (sec)
<u>Canyon / 11th</u>		East	West		
Cross EB Traffic	680 ft	28'	28'	3.9	6.0
Cross WB Traffic	310 ft	42'	32'	3.6	5.6
<u>9th / Walnut</u>		North	South		
Cross NB Traffic	305 ft	21'	36'	4.9	8.8
Cross SB Traffic	320 ft	32'	20'	4.2	6.4
<u>Arapahoe / 19th</u>		East	West		
Cross EB Traffic	590 ft	16'	26'	4.6	5.7
Cross WB Traffic	870 ft	29'	19'	4.7	7.4

Figure 13: Gap Rejection Distribution - Canyon Boulevard at 11th Street



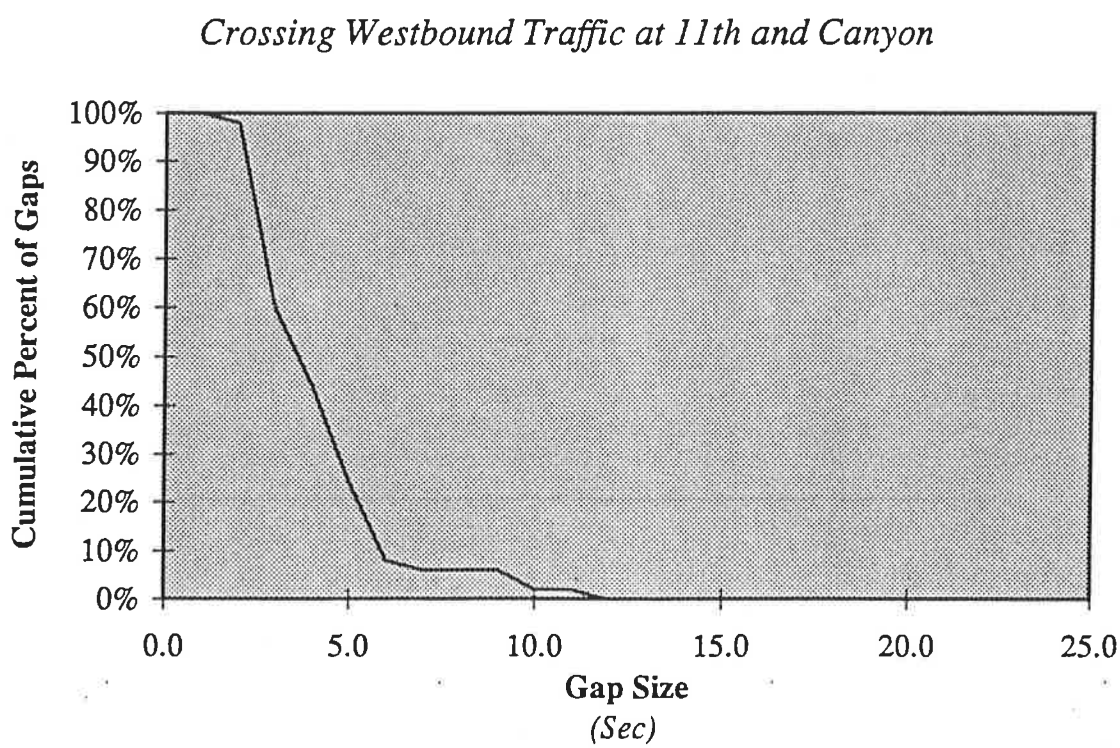
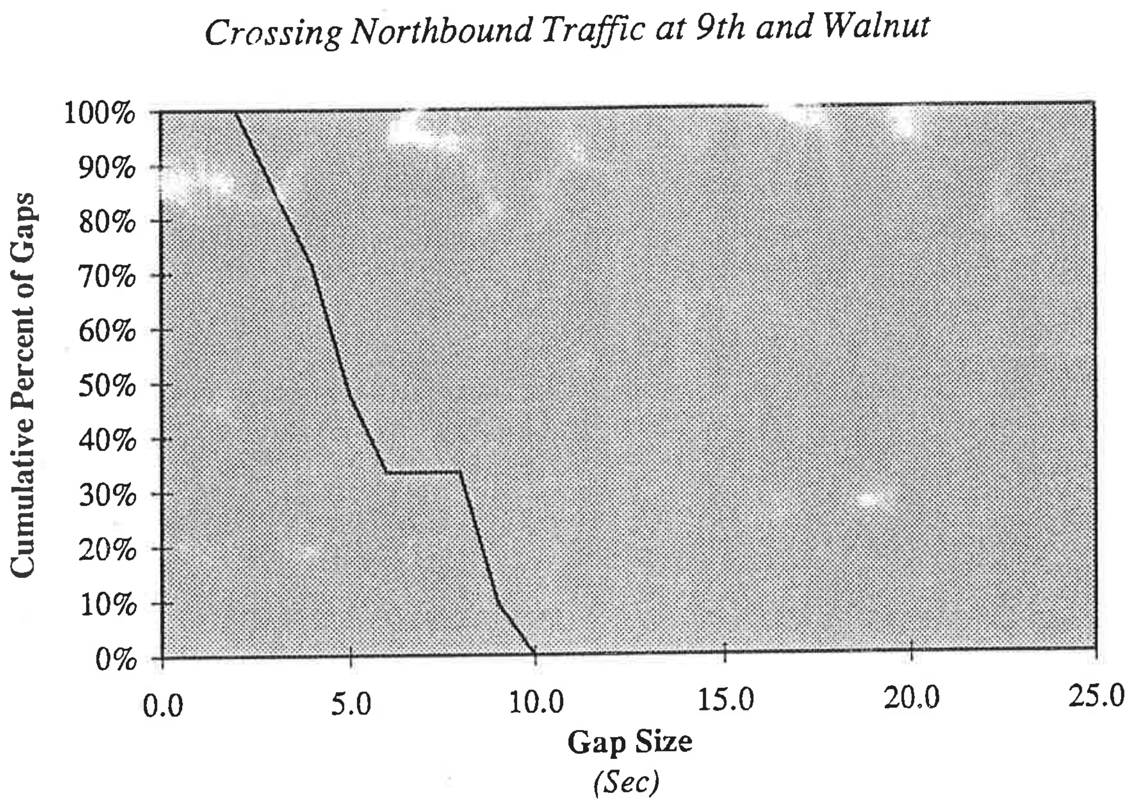


Figure 14: Gap Rejection Distribution - 9th Street at Walnut Street



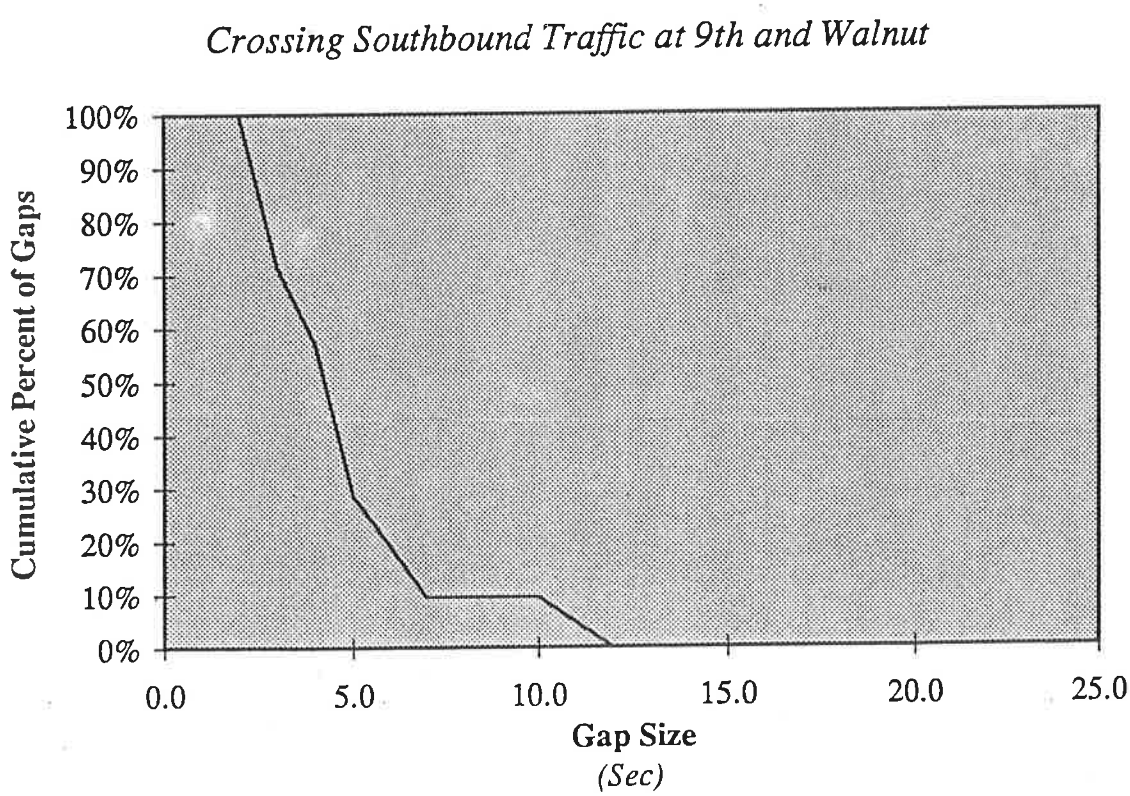
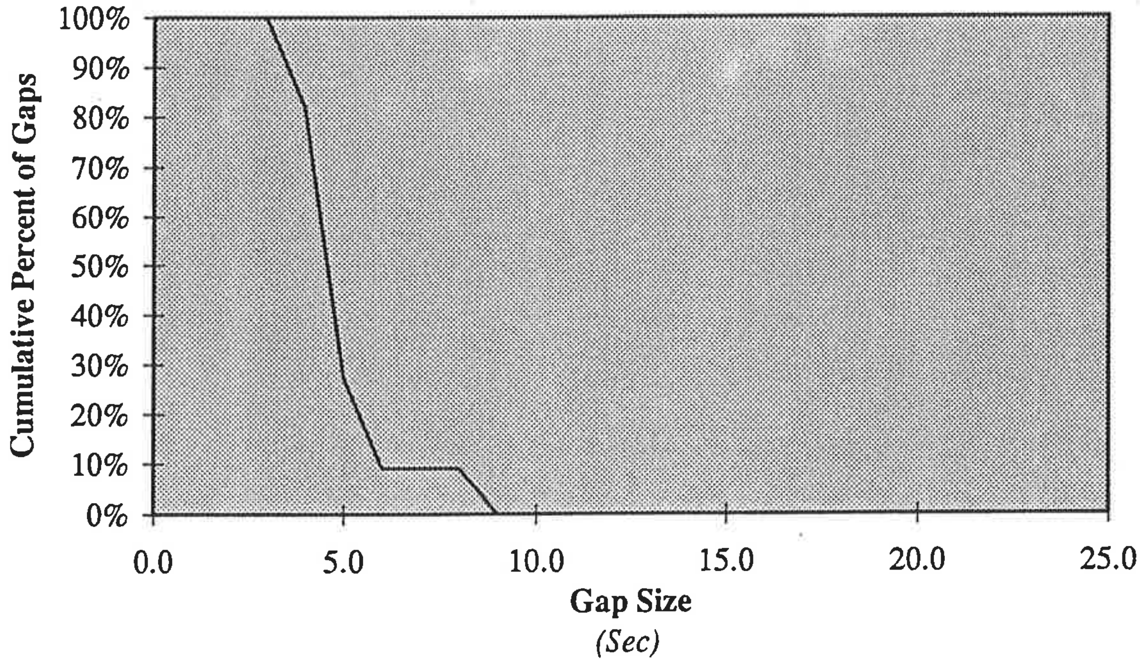
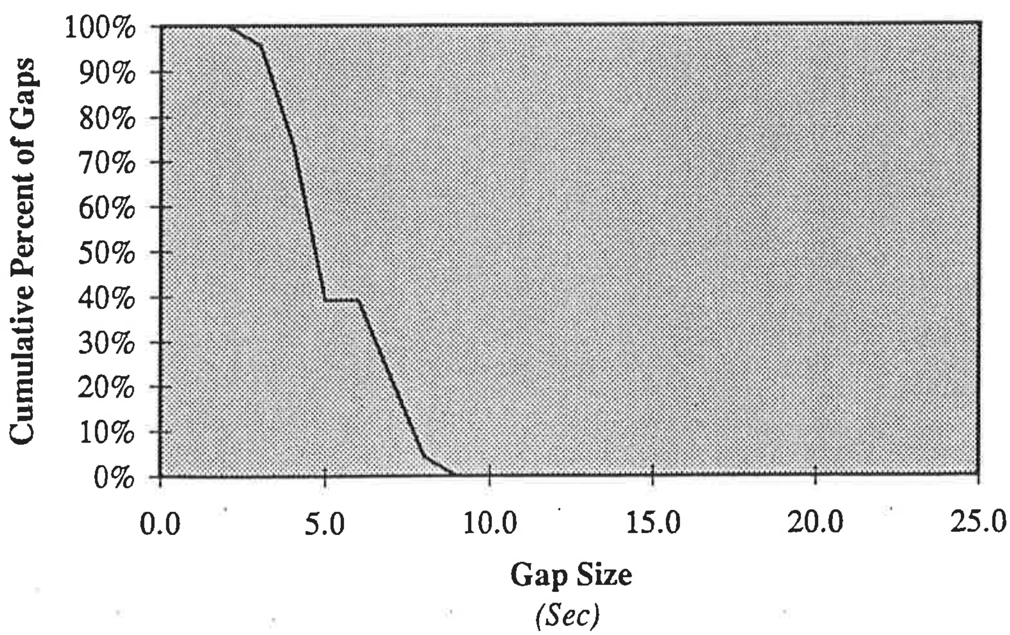


Figure 15: Gap Rejection Distribution - Arapahoe Avenue at 19th Street

Crossing Eastbound Traffic at 19th and Arapahoe



Crossing Westbound Traffic at 19th and Arapahoe



D. DISTRIBUTION OF VEHICLE GAPS

As previously mentioned, vehicle gap data was collected from the pedestrian crossing locations as well as two other locations. Results of the gap data are given in the table below.

Table 7: Vehicle Gap Data Summary

Location	Gaps in Northbound or Eastbound Traffic	Gaps in Southbound or Westbound Traffic	Combined Gaps
NS Traffic on 9th at Walnut			
15th percentile gap	1.4 sec	1.7 sec	0.8 sec
50th percentile gap	3.1 sec	4.0 sec	2.1 sec
85th percentile gap	9.2 sec	11.5 sec	4.8 sec
Number of gaps > 5 sec	210 gaps	238 gaps	178 gaps
Number of gaps > 10 sec	96 gaps	111 gaps	36 gaps
EW Traffic on Arapahoe at 19th			
15th percentile gap	1.5 sec	1.4 sec	0.8 sec
50th percentile gap	3.4 sec	3.0 sec	1.9 sec
85th percentile gap	11.1 sec	0.8 sec	4.6 sec
Number of gaps > 5 sec	153 gaps	129 gaps	119 gaps
Number of gaps > 10 sec	75 gaps	59 gaps	28 gaps
EW Traffic on Valmont at 34th			
15th percentile gap	0.8 sec	0.7 sec	0.3 sec
50th percentile gap	2.4 sec	1.9 sec	1.4 sec
85th percentile gap	8.4 sec	6.2 sec	3.5 sec
Number of gaps > 5 sec	217 gaps	181 gaps	144 gaps
Number of gaps > 10 sec	89 gaps	82 gaps	38 gaps
EW Traffic on Balsam at 13th *			
15th percentile gap	2.0 sec	2.6 sec	1.3 sec
50th percentile gap	5.3 sec	5.7 sec	3.2 sec
85th percentile gap	19.1 sec	19.8 sec	8.6 sec
Number of gaps > 5 sec	192 gaps	216 gaps	252 gaps
Number of gaps > 10 sec	121 gaps	121 gaps	81 gaps

* This data was collected prior to the installation of the four-way stop at the Balsam Avenue / 13th Street intersection. With the installation of the four-way stop, the intersection becomes a protected pedestrian crossing (by definition).

The data presented in the table above may be analyzed to compare the relative ease of crossing with and without a median. A five second gap was selected as an approximate acceptable gap to cross one lane of traffic and a ten second gap was selected as an approximate acceptable gap to cross two lanes of traffic. Comparison of the number of five second gaps to cross one direction to the number of ten second gaps to cross both directions shows that on average it is over five times easier to cross a single lane of traffic (as with a median) than it is to cross two lanes of traffic (as on a standard roadway with opposing traffic lanes).

E. ACCEPTABLE PEDESTRIAN DELAY

Pedestrian data at the three unsignalized crossing locations enabled the determination of how long pedestrians were willing to wait to cross the street. The amount of time a pedestrian waited for a gap affected their gap acceptance. This tolerance was indicated by the pedestrians' willingness to accept a gap of a given length that was equal to or shorter than a gap they previously rejected. There were twenty-six pedestrians which were in this category. A pedestrian was willing to wait an average of 15 seconds before accepting a gap length that was previously rejected. The 85th percentile delay was 22 seconds.

5. BICYCLE CROSSING SPEED

Bicycle crossing speeds were measured at the Balsam Avenue / 13th Street and Arapahoe Avenue / 19th Street intersections. Individual bike crossing speeds were calculated by dividing the crossing distance by the crossing time. The average bicycle crossing speed was 10 feet per second. The bicycle crossing speed data is given in Table 8.

Only bicycles which started from a stop were included in the crossing speed analysis. This limitation was set because most pedestrian crossings are likely to be stop-controlled, requiring bicyclists to stop prior to entering the crossing. Although some bicyclists may disregard the stop, use of the bike crossing speed measured from a stop is conservative and reduces the variability of trying to predict the percent of bicycle related stop sign violations.

Table 8: Bicycle Crossing Speeds

Location	Distance	Time	Speed	Distance	Time	Speed
Balsam/13th	45 ft (west side)	2.9	15.5	40.5 ft (east side)	4.0	10.1
		3.5	12.9		4.2	9.6
		3.9	11.5		4.4	9.2
		4.2	10.7		4.5	9.0
					4.7	8.6
					5.1	7.9
					5.3	7.6
					6.0	6.8
Arapahoe/19th	45 ft (west side)	3.0	15.0	45 ft (east side)	3.5	12.9
		3.2	14.1			
		3.3	13.6			
		3.7	12.2			
		3.9	11.5			
		4.4	10.2			
		4.9	9.2			
		5.6	8.0			
		6.1	7.4			
		6.1	7.4			
Avg Speed = 10.5 ft/s			Sample Size = 23		Std Dev = 2.6	

APPENDIX 2

SUMMARIES OF APPLICABLE TECHNICAL ARTICLES

MID-BLOCK PEDESTRIAN SIGNAL WARRANTS

TP-92143

The City of Boulder requested that we conduct a study of pedestrian signalization warrants and develop recommended warrants tailored to Boulder. The pedestrian signals refer specifically to mid-block locations. The following information is a summary of reference articles available on the subject.

Manual on Uniform Traffic Control Devices for Streets and Highways, U.S. Department of Transportation, Federal Highway Administration, 1988.

MUTCD PEDESTRIAN SIGNAL WARRANT: Warrant 3, Minimum Pedestrian Volume

A traffic signal may be warranted where:

- Pedestrian volume crossing the street during an average day is
  - 100 or more peds for each of any four hours, or
  - 190 or more during any one hour

- There are less than 60 gaps per hour in the traffic stream that are sufficiently long to allow pedestrians to cross the street. This condition must occur during the hour(s) that the pedestrian volume criteria is satisfied. (An adequate gap allows the pedestrian sufficient time to cross the street.)

- This warrant applies only to those locations where the nearest traffic signal is more than 300 feet away and a new signal would not unduly restrict platooned flow of traffic.

- Curb-side parking should be prohibited for 100 feet in advance of and 20 feet beyond the crosswalk.

MUTCD SCHOOL CROSSING WARRANT: Warrant 4, School Crossing

A traffic control signal may be warranted at an established school crossing when:

- The number of adequate gaps in the traffic stream during the period when the children are using the crosswalk is less than the number of minutes in the same period. (An adequate gap allows the pedestrian sufficient time to cross the street.)

- At non-intersection crossings, the signal should be pedestrian-actuated.

- Parking and other obstructions to view should be prohibited for at least 100 feet in advance of and 20 feet beyond the crosswalk.

- Special police supervision and/or enforcement should be provided for a new, non-intersection installation.

PEDESTRIAN-ACTIVATED FLASHING AMBER (OR RED) LIGHTS AT PEDESTRIAN CROSSOVERS [CROSSINGS]

Development of the Pedestrian Crossover as a Traffic Control Device in the Region Municipality of Ottawa-Carleton. D.M. Henderson and L.A. Ross

- Study results suggest that the modified pedestrian crossover can be an economical and effective element in the overall transportation system by permitting pedestrians to cross roadways safely and efficiently with a minimum of delay to both pedestrian and vehicular traffic.

- Pedestrian and vehicular delays are much lower at pedestrian crossovers than at pedestrian-actuated traffic control signals.

- Overhead illuminated signs are used above the traffic lanes at each pedestrian crossover to highlight the crossing area. It consists of:

  - The down-light which illuminates the pedestrian to on-coming vehicular traffic

  - The illuminated sign face which forms part of the box of the fixture

  - Flashing beacons mounted on each overhead fixture, with faces toward both the approach and leaving sides of the crossover

  - An audible signal that operates with the flashing beacons to provide pedestrians with an indication that they did something when they pushed the button

  - Symbolic signs that show a human hand pushing an activation button and a pedestrian with an outstretched arm (pointing), installed adjacent to the push buttons on the poles supporting the overhead fixtures

- Pedestrian compliance with activating the push-buttons at the flashing pedestrian crossover compared very favorably with the compliance observed at several traffic control signals.

- Public response in the City of Calgary has been overwhelmingly in favor of the pedestrian crossovers.

- Flashing duration of 10-12 seconds proved to be adequate. This may have to be adjusted based on street width. It is undesirable to have the beacons flashing after a completed pedestrian crossing, since motorists may come to ignore the flashing indication if it happens frequently. Pedestrians typically begin crossing the street within 2 seconds of pushing the button.

- After the provision of the pedestrian-activated flashing amber beacons on the overhead fixtures, many more pedestrians gave motorists a clear indication of their wish to cross the roadway. Significantly fewer motorists approaching the pedestrian crossover on the side nearest to the pedestrian failed to yield to the pedestrians after the overhead flashers were provided.

- The crossover devices provide more convenience to both pedestrians and motorists, less costly vehicular operation (less fuel is consumed if fewer vehicles are delayed for a smaller length of time), and less atmospheric pollution (vehicular emissions).

- The greatest delay and the highest incidence of near side motorists failing to yield occurred when the pedestrian gave no positive indication to drivers by just standing on the sidewalk and waiting for motorists to yield. (Delay includes pedestrian time waiting to cross and vehicle time waiting for the pedestrian to cross.)

- At pedestrian crossovers, motorists fail to yield to pedestrians more often when pedestrians do not clearly signal their intent to cross. This uncertainty leads to confusion and in some cases, potentially hazardous situations. It is necessary that both drivers and pedestrians be able to anticipate and predict the actions of the other (as much as possible). The very positive message provided by the flashing amber lights at the crossovers can assist in satisfying this requirement.

- Another item being investigated is the provision of a lighted response to the push button actuation at pedestrian crossovers. To prevent motorist confusion, this would be visible only to pedestrians (possible Econo-Lite product).

- Pedestrian Crossover Warrants for the Regional Municipality of Ottawa-Carleton Transportation Department:

  - The installation of a pedestrian crossover is warranted when the proposed location plots within the warranted zone on both of these graphs:
    -- "Graph for Pedestrian Crossover Evaluation-Delay Warrant"
    -- "Graph for Pedestrian Crossover Evaluation-Volume Warrant"

  - There are at least 200 weighted pedestrian crossings in an eight hour period. A factor of two will be applied to senior citizens and children under 12 years of age who are unassisted by school patrol, school crossing guards, or police.

  - The location is more than 180m (600 ft) from adjacent traffic control signals or pedestrian crossovers.

  - The 85th percentile speed on the roadway is less than 65 km/hr (40 mph) off peak.

  - The roadway is undivided.

  - The roadway width is not greater than four traffic lanes for a two-way street.

  - The roadway width is not greater than three lanes wide for a one-way street.

  - Vehicular volumes on the roadway are less than 15, 000 during a 12 hour period (7:00 a.m. to 7:00 p.m.).

  - No visibility problems exist due to horizontal or vertical roadway alignment or objects.

  - Offset intersections, pedestrian visibility problems, roadside distractions or heavy turning movements are not present.

  - A consistent violation of the stopping prohibition would not be expected.

  - Constant interruption of vehicular traffic would not occur.

  - Sidewalks necessary for the safe and effective use of a pedestrian crossover are available or will be provided prior to a pedestrian crossover being installed.

Traffic Operational Characteristics

Two principal types of operational surveys were carried out in order to determine the inherent operational characteristics of the several traffic control devices under study.

The first survey type (observation survey) consisted of gathering data relating to the major operational aspects of these devices. These surveys were conducted at the two locations provided with the prototype pedestrian crossovers equipped with pedestrian-activated flashing amber beacons, at five locations controlled with pedestrian-actuated traffic control signals and at five locations controlled with pedestrian crossovers.

The second survey, the driver response survey, was carried out only at the two prototype pedestrian crossover locations. This survey measured the effectiveness of several different means of informing motorists of a pedestrian's wish to cross the roadway at a pedestrian crossover. This survey w a controlled study conducted by having a traffic surveyor cross the roadway a specified number of times after using a particular method of indication at the curb to inform approaching motorists of the intent to cross. In each case the person crossing timed his indication to coincide with the presence of a near-side vehicle at a point 30 m away on the approach to the cross-over. The surveyor did not commence the crossing of the road-way until it was apparent that the nearside vehicle would yield

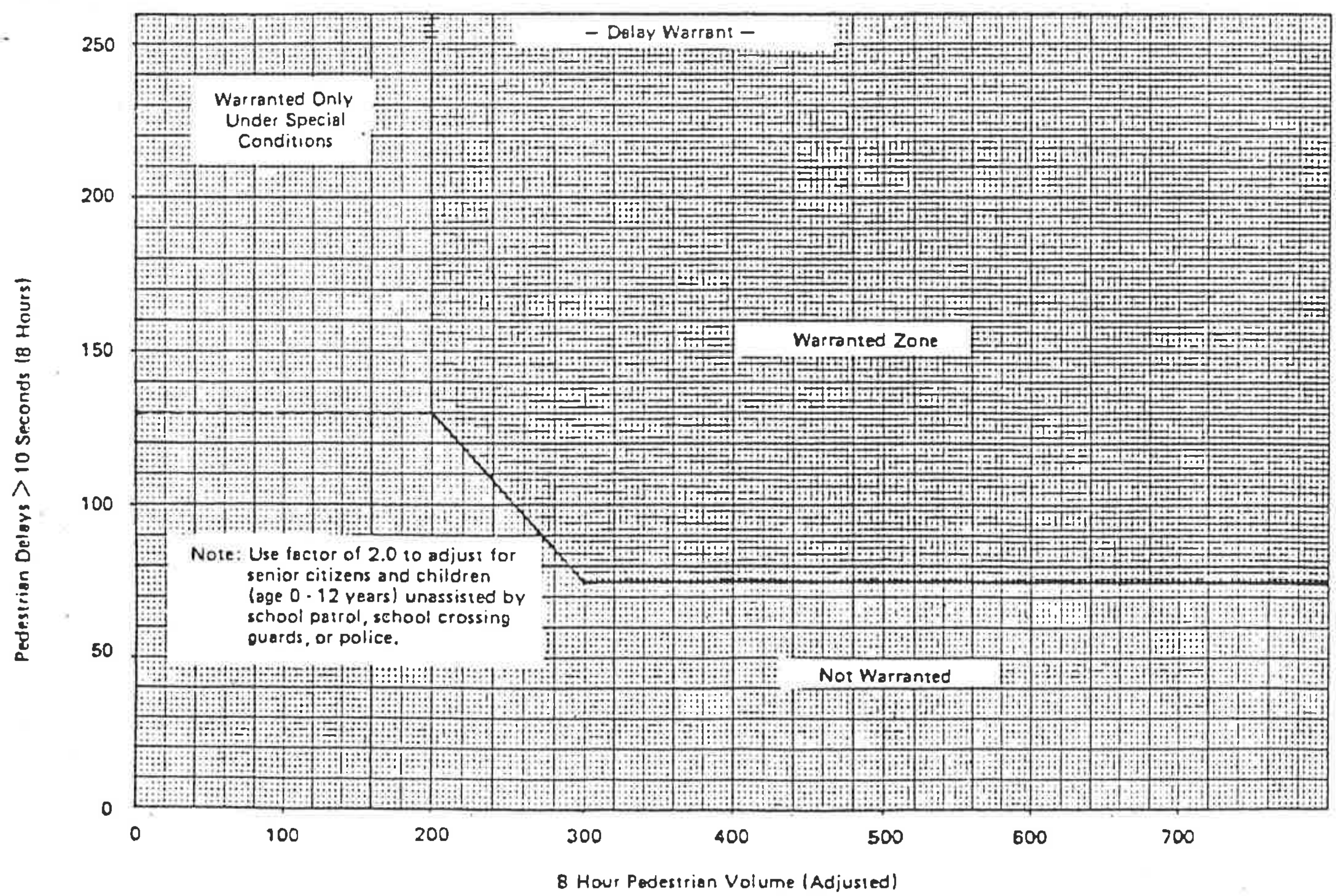
Table 8 Pedestrian and Vehicular Observation Study Summary — Laurier Avenue at Sweetland Avenue (Two-lane Roadway)

	Number of pedestrians surveyed	Average pedestrian group size	Pedestrians in groups pointing	Pedestrians in groups activating flashers	Groups with largest delay >5 sec.	Vehicular queues with largest delay >5 sec.	Average number of delayed vehicles per device use[1]	Nearby pedestrians crossing outside the crosswalk
"Before"-flashing feature provided (Surveyed Apr. 1977)	289	1.4	34%	0%	4%	9%	0.9	16%
"After" flashing feature provided (Surveyed May 1977)	254	1.6	1%	77%	4%	17%	1.2	10%
"After" advance flashers installed (Surveyed May 1977)	235	1.6	3%	72%	5%	18%	1.2	11%

1 Total vehicles reducing speed to less than 6 km/h on both approaches to the device.

Note Old white-type lighting fixtures existed at Laurier Avenue and Sweetland Avenue before the pedestrian-activated amber flashers were provided.

Fig. 4 Graph for Pedestrian Crossover Evaluation



The greatest delay and the highest incidence of nearside motorists failing to yield occurred when the surveyor gave no positive indication to drivers by just standing on the sidewalk and waiting for motorists to yield.

Costs

Estimated average installation costs for the traffic control devices considered in this study are shown in Table 10. The Ontario Ministry of Transportation and Communications (MTC) currently provides a subsidy of approximately 60 percent of the installation costs for pedestrian crossovers and 50 percent of the installation costs for warranted traffic control signals.

Discussion of Results

The traffic collision statistics from Table 3 show that the pedestrian collision rate on multi-lane roadways is lower at traffic control signals than at pedestrian crossovers equipped with the old white-type lighting fixtures. No significant difference in pedestrian collision rate exists between traffic control signals and pedestrian crossovers equipped with the old white-type lighting fixtures on two-lane roadways.

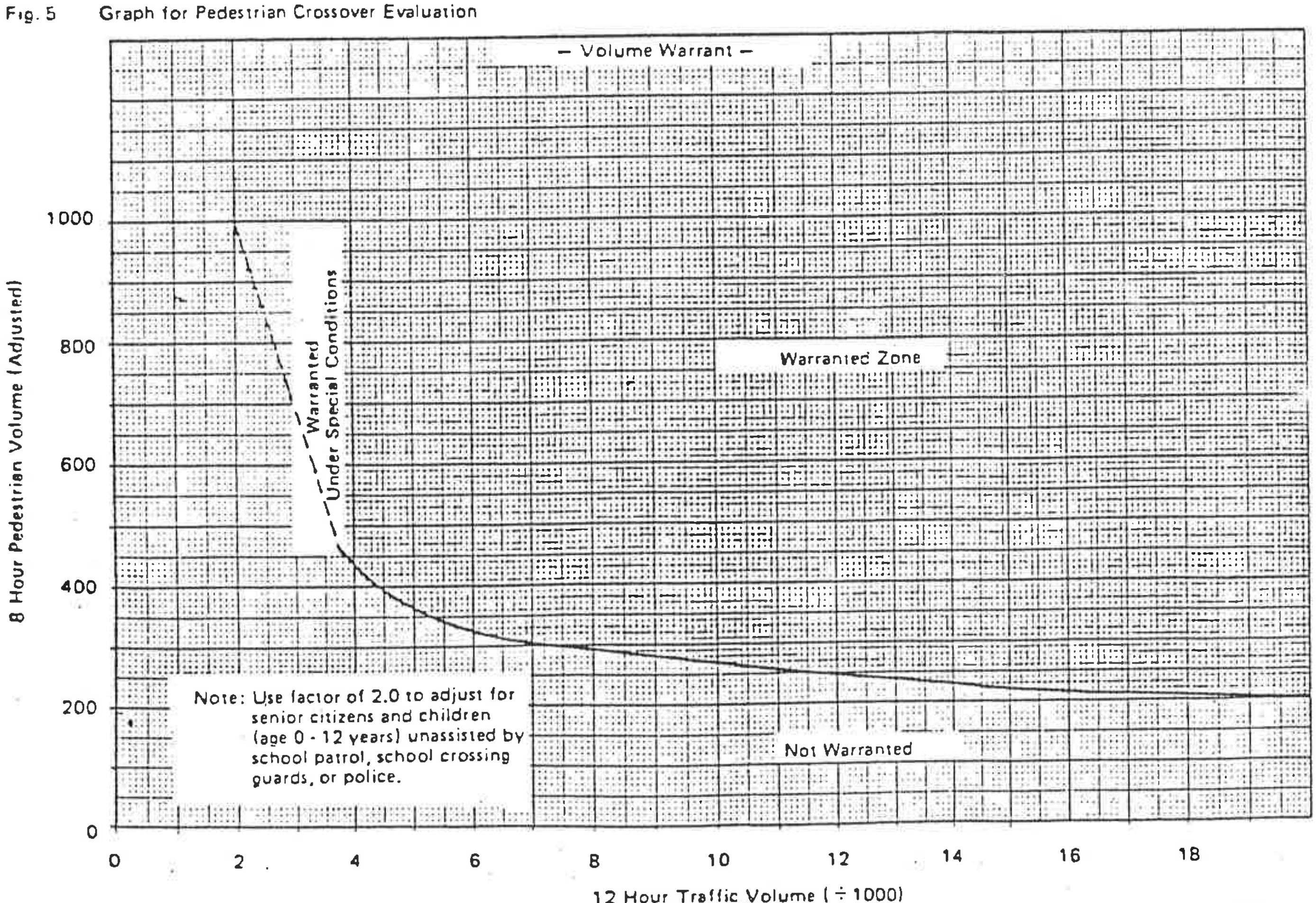
The traffic collision statistics from Table 2 show that a significant reduction in total traffic collision frequency occurred at nine pedestrian crossover locations, after the provision of the upgraded amber fixtures. Although not statistically significant, a 50 percent reduction in the number of pedestrian collisions was also recorded at these locations.

From Tables 7 and 9 it can be seen that motorists at the two prototype pedestrian crossover locations failed to yield to pedestrians on significantly fewer occasions after the pedestrian-activated flashers were provided. Therefore, considerably fewer pedestrian-vehicular conflicts occurred, thus suggesting a lower pedestrian collision rate at these locations. On this basis, it is anticipated that the effective warning provided to approaching motorists by the prototype pedestrian crossover, would precipitate an even further reduction in total traffic collisions (mainly rear-end collisions) than the reduction already experienced at the locations provided with only the upgraded amber lighting fixtures.

The results presented in Tables 4 and 5 show that both pedestrians and motorists experienced much less delay at the existing pedestrian crossovers than at the pedestrian-actuated traffic control signals. Pedestrian and vehicular delays at the two prototype pedestrian crossover locations were also much lower than at the traffic control signals. In addition, more vehicles were delayed per device actuation at the traffic control signals than at the pedestrian crossovers. Therefore, the existing pedestrian crossover devices and the prototype pedestrian crossover devices provided more convenience to both pedestrians and motorists, less costly vehicular operation (less fuel is consumed if fewer vehicles are delayed for a smaller length of time), and less atmospheric pollution (emissions from vehicular exhaust systems).

Only 34 percent of the pedestrians at the existing pedestrian crossovers gave a positive indication (pointed) to approaching motorists before they crossed the street. However, 74 percent of the pedestrians at the two prototype pedestrian crossovers gave a positive indication to motorists by activating the

Fig. 5 Graph for Pedestrian Crossover Evaluation



FHWA PEDESTRIAN SIGNALIZATION ALTERNATIVES

Pedestrian Signalization Alternatives. U.S. Department of Transportation, Federal Highway Administration, Report No. FHWA/RD-83/102; July 1985.

Summary and Conclusions:

- Pedestrian volume is the single most important variable in explaining the variation in pedestrian accidents and a significant, direct relationship exists. The most important break points occur at pedestrian volume levels of 1,200 and 3,500 pedestrians per day.
- Traffic volume is the second most important variable in explaining pedestrian accidents, and it also has a significant, direct relationship to pedestrian accidents. The important break points occur at traffic volume levels of 27,500 and 18,000 vehicles per day.
- The presence of exclusive-timed, protected pedestrian intervals (including scramble-timed intersections) was associated with significantly lower pedestrian accident experience when compared to locations with either concurrently-timed pedestrian signals or no pedestrian signals, when controlling for other important data variables.
- The use of concurrently-timed pedestrian signals was found to have no significant effect on pedestrian accident distributions (based on chi-square test) or pedestrian accident frequencies (analysis of variance and covariance).
- The use of pedestrian indications with concurrent timing was not found to be effective in reducing pedestrian accidents. Possible reasons are:
  - Poor pedestrian respect and compliance to pedestrian signal indications
  - Pedestrian signal indication may tend to create a false sense of security and pedestrians do not cross with caution
  - Use of the flashing WALK has been shown to be ineffective in adequately warning pedestrians to watch for turning vehicles
  - The flashing DON'T WALK is not understood by many pedestrians
  - Pedestrian actuation devices are used too infrequently so the use and respect for pedestrian signals may be minimal at these locations
- The existing MUTCD Minimum Pedestrian Volume Warrant is highly impractical for most real-world conditions and is largely ignored by the traffic engineering community. An improved warrant was developed based on minimum pedestrian volumes for either 4 hours (60 or more per hour), 2 hours (90 or more per hour), or 1 peak hour (110 or more) crossing the major street, combined with less than 60 acceptable gaps per hour during the same period. By coincidence, the proposed Minimum Pedestrian Volume Warrant has similarities to the existing Canadian Warrant and the warrant recommended by Box in 1967. Another recent FHWA study by Nuedorff in 1983 ("Candidate Signal Warrants from Gap Data") also recommended the adoption of this proposed warrant.

Revised Pedestrian Signal Warrant (Chapter II)

- [1978] MUTCD Pedestrian Volume Warrant is unrealistically high. In most cities, few or no traffic signals can be justified based on this warrant. (About 7,600 peds required at a typical 4-legged intersection)

- [1978] warrant is not adequately sensitive to gaps in traffic or to such related traffic and highway variables as:
  - Traffic speed (25 mph versus 35 mph)
  - Street width (undivided streets of 20 ft versus 50 ft)
  - Vehicle volumes (volumes of 700 per hour versus 2,000 per hour)
  - Vehicle arrival rates (random versus traffic queues)
  - Pedestrian walking speeds (2.5 ft/sec versus 4 ft/sec)

- A warrant based on a minimum volume of pedestrians for a specific period, and conforming to either a minimum delay per pedestrian or a maximum number of adequate gaps per unit of time (1 hour, 4 hour period, etc.) would provide the best approach for a revised warrant.

- The duration of time required should be somewhere between one to four hours, since volume data for less than one hour is likely to be unreliable due to large fluctuations associated with short periods of time.

- The use of several warrants covering different time periods may also allow for more widespread application of the warrant. For example, a signal could be warranted based on either a one hour warrant, a two hour warrant or a four hour warrant. The requirement of pedestrians per hour would be higher for the one hour warrant than for the two hour warrant.

- Rather than consider only the pedestrian volume on the highest leg of the intersection, the warrant should be expressed in terms of pedestrians crossing the highest volume street (or the total volume crossing at a midblock location).

- After trying several groupings of pedestrian volume, the breakpoint was found to occur for a daily pedestrian volume level of 1,200. In fact, for the 609 locations with pedestrian volumes less than 1,200 the mean pedestrian accidents (per location per year) was 0.178 as compared to 0.553 for the 680 locations with above 1,200 pedestrians per day. Note, it will probably not be exactly the same breakpoint for pedestrians accidents at non-signalized intersections.

- A daily pedestrian volume of 1,200 at four-legged intersections corresponds to a pedestrian volume of 750 crossing the major street (the two highest volume legs). Based on the hourly pedestrian distributions, this would convert to the following:

VOLUME PERIOD	EQUIVALENT PEDESTRIAN VOLUME (nearest 10 pedestrians)
24 Hour Volume	750
1st Highest Hour	110
2nd Highest Hour	90
4th Highest Hour	60

- A pedestrian signal warrant must consider not only pedestrian volumes, but also the time available for pedestrians to cross the street (i.e., the available gaps in traffic). The number of adequate gaps in traffic is directly related to various combinations of traffic speed, volume, and arrival patterns. Further, the number and duration of gaps needed for safe pedestrian crossings is a function of street width, pedestrian walking speed, pedestrian volume, and pedestrian group size.

- In the absence of additional objective information, the recommended minimum pedestrian volume criterion was selected as follows:

  - The minimum required pedestrian volume crossing the major street per hour for an average day must be:
    -- 60 or more for each of any four hours, or
    -- 90 or more for each of and two hours, or
    -- 110 or more during the peak hour

  - In addition to a minimum pedestrian volume of those stated above, the number of adequate gaps (time needed for a pedestrian to cross the street, as prescribed in the MUTCD) in the traffic stream should be less than 60 per hour during the same period when the pedestrian volume criterion is satisfied.

  - The crossing must be at least 150 feet from another established crosswalk and/or 300 feet from an adjacent signal.

- A special traffic signal is warranted to accommodate elderly and/or handicapped pedestrians at locations meeting the following conditions:

  - The location is at least 150 feet from a protected crossing.

  - The number of elderly (60 years of age or older) and/or handicapped pedestrians is at least:
    -- 30 or more for each of any four hours, or
    -- 45 or more for each of any two hours, or
    -- 60 or more per hour in the peak hour

  - During the hour that pedestrian volume is the highest, there must be less than 60 adequate gaps. Walking speeds of 2.5 ft/sec (per ITE study) should be used when computing adequate gap time.

  - At crossings where traffic signals are installed based on this warrant, pedestrian actuation should be provided with pedestrian indications. Also, advance signing and/or flashing beacons can be provided to alert motorists to use added caution.

UNSIGNALIZED PEDESTRIAN CROSSINGS: NEW ZEALAND'S TECHNICAL RECOMMENDATION

Roger C.M. Dunn. ITE Journal, September 1989, pp. 19-23.
[NOTE: a copy of this document can be obtained from New Zealand's National Roads Board]

Zebra crossing: unsignalized, marked pedestrian crossing
Pedestrian crossing: refers to an unsignalized but striped crossing, located at either an unsignalized intersection or midblock.

Background

- Signalized crossings had fewer safety problems than unsignalized crossings.
- Unsignalized crossings had a range of safety problems, but those considered to be major problems pertained to non-school crossings as well.
- The most significant safety problem identified was that of vehicles parking or stopping too close to the crossing, thereby severely restricting visibility.
- School crossings that had the most acute safety problems were in areas that usually had one or more of the following traffic conditions: high vehicle flows, high speeds, more than two lanes, or poor visibility.

Intervisibility

- Accidents at a pedestrian crossing generally occur when the driver and/or the pedestrian is not aware of the other's movement or presence.
- Intervisibility is the concept of visibility and communication between the pedestrian and driver that is essential to safe and efficient operation of pedestrian crossings.
  - Visibility in both directions: from pedestrian to driver and from driver to pedestrian
  - Communication: namely, in terms of an appropriate physical environment, so as to enable effective communication not only from pedestrian to driver, but also from driver to pedestrian
- The proportion of drivers who stopped increased significantly if their approach speed was 50 km/hr (30 mph) or less.
- The readiness of the drivers to stop was substantially greater when the pedestrian clearly indicated [pointed] with an arm or hand signal his intent to cross.
- Approximately 50% of the conflicts (i.e., interactions requiring evasive action) at crossings include errors or mistakes by drivers, and the driver's error or mistake is usually that of reacting too slowly to the actions of the pedestrians (NOT of approaching too fast, as is commonly thought).
- The main requirements for improving pedestrian safety at crossings are:
  - The crossing, including the curbside ends, must be visible to approaching drivers at a sufficient time and distance so as to allow them to stop when necessary.
  - The curbside ends of the crossing must provide a suitable physical environment for pedestrians to make sensible decisions about crossing the road and then to communicate their intentions to any oncoming drivers.

- The overall conspicuity of the physical devices (namely, poles, markings, and lighting) at pedestrian crossings must be sufficient to prepare a driver to stop, if necessary.

Intervisibility Distance

- The required intervisibility distance should be equivalent to the safe stopping sight distance based on appropriate parameters.

- Recommended intervisibility distances given in TR11 (Table 3) are well above the minimum visibility distance of 30 m (speed limit of 50 km/hr), as specified by the New Zealand Traffic Regulations.

Crossing Length and Refuge Islands

- A major pedestrian hazard is vehicles parking too close to the crosswalk.

- Another hazard is vehicles passing other vehicles which are stopped for pedestrians on the crosswalk.

- Auckland: investigation of pedestrian accidents on high-flow arterials indicated a disproportionately high level on multi-lane roadways (i.e., more than two lanes) with unsignalized pedestrian crossings.

- Recommend roadway narrowing and/or a central refuge island to provide desirable pedestrian parking. Roadway narrowing also enables curbside parking to be retained.

Poles and Belisha Beacons

- It is common practice in New Zealand to use poles with belisha beacons (yellow globes that flash at night).

- To improve the conspicuity of crossings, the standards of installation of poles and beacons were raised:

  - Poles preferably should be up to 300 mm in diameter, at least 3 m in height, and have white bands of reflective sheeting; and

  - Belisha beacons should be used at all crossings, and located at least 3 m above the pavement and within 300 to 600 mm of the curb

Illumination/Floodlighting

- Nighttime pedestrian/vehicle accidents are disproportionately represented in the accident records

- Research clearly indicates the extreme difficulty drivers have in perceiving a pedestrian who is crossing in a poorly lit roadway

- TR11 requires all pedestrian crossings to be specifically illuminated or floodlit (i.e., to higher levels than the surrounding roadway and footpath area)

Warrant and Locational Criteria

- Analytical research showed that the flow criteria were substantially changed, depending on the relative value (or costs) of pedestrian waiting time to vehicle delay time (including stopping), so the flow criteria adopted in the previous warrant was retained (Table 5).

- The provision of a pedestrian crossing is unlikely to improve a situation where pedestrians can cross the roadway in reasonable safety or could do so with the addition of refuge islands.

- Justification for a pedestrian crossing should not be based only on peak pedestrian and vehicle flows.

PEDESTRIAN DELAY AND PEDESTRIAN SIGNAL WARRANTS

G.F. King. Transportation Research Record No. 629

The concept of better service manifests itself by reducing the average or maximum delay: a reduction in the probability of stops or a reduction in accident potential. This paper is concerned with using pedestrian delay as the boundary criterion in traffic signal warrants.

- The main rationale underlying a pedestrian warrant is to determine those traffic flow conditions that are characterized by inadequate gaps in the traffic stream that affect the safe passage of pedestrians.

- A rational pedestrian warrant should be based on the following considerations:

  - An acceptable level of average pedestrian delay
  - A tolerable level of maximum (i.e., 95th percentile) pedestrian delay
  - An equitable allocation of total delay between the pedestrian and vehicle components of the traffic stream.

- For the purposes of developing a pedestrian warrant, we selected 30 seconds as an acceptable level of mean pedestrian delay and 60 seconds as a tolerable level of maximum (i.e., 95th percentile) delay.

- Since the use of signals would not be considered at extremely low pedestrian flow levels, a lower limit of pedestrian hourly demand must be set. Current MUTCD sets uses 150 peds/hr. Suggest a proposed pedestrian warrant be subject to these two lower bounds:

  - An aggregate pedestrian delay of one hour per hour, and
  - A minimum pedestrian volume of 100 per hour

- A proposed pedestrian warrant for the undivided highway case is shown in Figure 7. The minimum pedestrian volume that warrants a signal is read [from the chart], and if the actual pedestrian volume exceeds this value, a signal is warranted.

- The curves shown in Figure 8 apply to divided highways. These curves are based on the assumption of approximately equal directional traffic volume split.

- The explicit assumptions of isolated intersections (i.e., random arrivals) at mid-block pedestrian locations should be kept in mind when evaluating these proposed warrants. Although the proposed warrant in general applies to this set of conditions, it can be extended, in general, to crosswalks at intersections.

- The numerical warrants for both mid-block and intersection locations are presented in Figures 7 and 8. Before signals are installed, these warrants should be met or exceeded for 4 hours on an average weekday. Alternatively, the warrant could be met or exceeded for 10 hours on any weekend if at least 3 hours are on the day with lighter volumes.

KNOWLEDGE AND PERCEPTIONS OF YOUNG PEDESTRIANS

Martin L. Reiss. Transportation Research Record No. 629

ABSTRACT: The progress of a research study on school-age pedestrians has been previously reported in a paper that dealt with the behavior of drivers in relation to the existing signing at four school sites in three states. That research study has now been completed, and this paper deals primarily with the findings regarding youngsters in the 5 to 14-year-old age group. Data are provided on the accident experience of the young pedestrians and on their behavior, attitudes, and knowledge. Students in sections of the eastern US were observed walking to school and were then surveyed on their pedestrian behavior and knowledge. Significant differences by age groupings were noted for both the accident data and knowledge responses.

The study objective was to develop guidelines for the protection of young pedestrians (age 5 to 14 years) walking to and from school. These guidelines were based on field surveys of the young pedestrian and the driver regarding designated school zones and specific school-crossing protective devices.

- National accident data:
  - 48% of pedestrian injury accidents are to young pedestrians under 15 years old
  - 5-14 year group represents 38% of all pedestrian accidents; this population has almost four times the number of accidents than any other age group.

- Urban accident data:
  - Study indicates that pedestrians between 5 and 14 years of age represent 34% of the pedestrian accident data base
  - The period between 2:00 and 4:00 p.m. represent the highest accident time period for this population
  - This age group was most likely to become involved in an accident
    - on a weekday
    - in the first lane of a two-lane road
    - in a residential area
    - in an area without traffic controls
    - with a car going straight
  - This age group was also involved in accidents when
    - they did not cross at an intersection or crosswalk (mid-block)
    - the driver's vision was blocked by a parked vehicle
    - the pedestrian was running
    - the pedestrian was crossing from behind a parked vehicle

- School walking trip accidents: the data in this study are in agreement with previous studies which indicate that 10 to 20% of young pedestrian accidents occur during the school walking trip.

- There is a near-monotonic relation between the age and the accident involvement rate for the 5 to 14-year-old population. The youngest students are considerably over-represented in the school-trip accident data and the oldest students are under represented.

- One hypothesis for the over involvement of the youngest pedestrians is their degree of exposure to vehicles as pedestrians; however, this does not prove to be the case.

- The analysis of young pedestrians who were observed during a 20 minute period after school showed a highly significant increase in exposure (road crossings and traffic density encountered) with age. The risk per road crossing and risk per encounter with a car decrease with age as does the accident involvement rate.

- Another study describes the most frequent actions (comprising over 68% of the young pedestrian accidents) in decreasing order: darting into the street, crossing mid-block, and playing in the street. Other recurring characteristics involved in accidents in this study were children running, pedestrians not crossing at the intersection or crosswalk, and driver's vision blocked.

- Accident causation: one study suggests that the average child does not attain the requisite degree of maturity as a pedestrian until the child is between the ages of 9 and 12. It points out that:

  - The diminutive stature of children makes it difficult to judge a traffic situation

  - Children are incapable of distributing their attention because they concentrate on one thing at a time--often play--or take a vague overall impression.

  - They cannot distinguish between right and left.

  - They have difficulty discriminating the direction of sound.

  - Many children believe the safest way to cross a street is to run.

- The accident victims differ significantly from their controls by having less parental supervision and by coming from homes and neighborhoods that had fewer play areas.

- Survey of child pedestrians: in general, the pattern of responses indicates a progression of understanding and capability from the kindergarten to the eighth grade students. The youngest students have less walking exposure, particularly alone, and usually cross at protected locations where there are crossing guards. These students generally do not relate to or indicate an understanding of traffic control devices and safety techniques other than crossing guards.

- As age increases, a greater proportion of the students will cross on the green signal. This relation between the students' increased knowledge of traffic control devices and age closely matches the decreasing rate of student involvement in accidents: There is a near-monotonic relation between age and accident involvement.

- For the youngest students, the accident risk and lack of knowledge concerning traffic control devices should be considered in relation to how those children choose their school routes and who can influence their choices.

- Significantly more younger students (who need the most help) than older students indicated they would change their route [to school] if told to do so by their parents. These results appear to indicate differing influences on the routes of the students at various age levels and may have implications for channels of information to promote change.

PROPOSED WARRANTS FOR SOUTH-AFRICAN MID-BLOCK PEDESTRIAN CROSSINGS

Ribbens & Bahar; National Institute for Transport and Road Research, South Africa; Oct 1982

SYNOPSIS: Warrants for the provision of uncontrolled and signal controlled mid-block pedestrian crossings are proposed in this report. Based on empirical data, pedestrian walking speed is separately established for typical and elderly pedestrians. Speed limit, different effective widths of roads and direction of flow are considered in the determination of the proposed warrants. It is concluded that the adoption of the warrants will lead to a reduction in the number of inappropriate installations to be seen in our cities and towns. In addition, publicity, education and, most of all, effective law enforcement are needed to improve the safety of pedestrian crossing facilities in South Africa.

- WARRANTS FOR UNCONTROLLED MID-BLOCK PEDESTRIAN CROSSINGS:
  - Block pedestrian crossings... should be provided in urban areas at places where it is desirable to assign priority to pedestrians crossing the roadway.

  - Block pedestrian crossings should only be laid down where distinctive concentrations of pedestrians regularly cross a roadway such as opposite arcades, cinemas and other centers of attraction for pedestrians located on a busy road.

- WARRANTS FOR SIGNAL CONTROLLED MID-BLOCK PEDESTRIAN CROSSINGS: The installation of traffic control signals will be warranted when... the number of pedestrians crossing a street during each of any 4 hours of a normal day exceeds 200 per hour at places farther than 150 m from any signal controlled pedestrian crossing and the vehicular traffic volume in both directions exceeds 400 vehicles per hour during each of the same 4 hours.

- EVALUATION: Uncontrolled mid-block crossings warrants are unusual since they are subjective; no volumes for pedestrian or vehicular flow are specified. The result is unnecessary crossings at locations with adequate gaps for pedestrians to cross safely. This has a detrimental effect on pedestrian safety, since motorists often ignore these crossings. Existing warrants for signal controlled crossings are inflexible since road width, vehicular speeds, pedestrian walking speeds are not considered.

- Basic principles in the determination of warrants
  - Safety and circulation:
  - Vehicular/pedestrian separation

- PROPOSED WARRANTS FOR MID-BLOCK PEDESTRIAN CROSSINGS:
  - Preliminary considerations: low vehicular and/or pedestrian volumes do not justify facilities for pedestrians to cross the road. Therefore, minimum volumes need to be established.

  - Road and traffic characteristics: warrants should take into account road width, speed limit, and the direction of flow.

  - Pedestrian characteristics: a study of pedestrians resulted in the following typical walking speeds
    1.37 m/sec for typical pedestrians
    1.18 m/sec where elderly people predominate

  - Minimum vehicular volume warrant: from observations, pedestrians become impatient after waiting 30 seconds. Minimum vehicular volumes at various speeds and corresponding to a 30 second pedestrian delay are given in Table 4.3.

- Minimum pedestrian volume warrant: Table 4.4 shows the number of safe crossing gaps/hour corresponding to the minimum vehicular volume warrants. This report proposes no pedestrian crossing facility be provided where pedestrian volume is less than 50 peds/hour.

- Maximum pedestrian volume warrant: As pedestrian volume increases, vehicular delay also increases. Pedestrians will create a serious interruption to traffic when the uncontrolled mid-block crossing is available to vehicular traffic less than 60% of the time. At this point, the crossing should be signalized. Maximum acceptable pedestrian volumes are shown in Figures 4.2 through 4.13.

EVALUATION OF THE PROPOSED GUIDELINES FOR UNCONTROLLED MID-BLOCK PEDESTRIAN CROSSINGS

H. Ribbens; National Institute for Transport and Road Research, CSIR, South Africa; April 1987

Guidelines for the layout and signing of uncontrolled mid-block pedestrian crossings proposed in Technical Report RF/4/83 have been implemented and are evaluated in this report. The guidelines recommended new road signs and markings which would improve both road-user behavior and the conspicuity of the crossings. Two types of area were chosen for testing: where drivers readily give way [yield] to pedestrians and where drivers fail to give way. Video survey showed that more drivers gave way to pedestrians with the new system. The roadside survey indicated that the majority of the drivers (75%) considered the new system to be an improvement on the old system. Accident analyses established that the new system did not cause more accidents than the old system. The three local authorities that implemented the new system agreed that it improved pedestrian safety and conspicuity.

Comments from Traffic Officers

- Periodic observation of the mid-block pedestrian crossings and signs indicate a more acceptable awareness of pedestrians by motorists
- Follow-up law enforcement is essential
- Zig-zag crosswalk lines immediately attract the attention of motorists
- Volume of pedestrians using the crossings increased
- Motorists don't like to stop at crossings because they are afraid of being rear-ended
- Accident types recorded were pedestrian/vehicle and rear-end vehicle collisions

Road markings

- Zig-zag markings: improve conspicuity of the mid-block crossing; prohibit vehicles from stopping or parking in advance of ped crossing; ban on overtaking or lane changes in the zig-zag zone; peds may not cross the road in the zig-zag zone except at the crossing
- Crosswalk markings: (longitudinal) should continue to be used for uncontrolled mid-block crossings and their width should be proportional to pedestrian flow (2.4 m wide plus 0.6 m for each 125 peds/hour above 500 during the 4 peak hours)
- Yield line: located 6 m in advance of the pedestrian crossing
- No parking lines: should be applied from the yield line to 9 m beyond the crossing to prevent stopping in the vicinity of the crossing and to improve visibility

Proposed amendments to road traffic ordinances

- Driver of vehicle must yield right-of-way to pedestrian in the crossing
- Parking/stopping is prohibited within 30 m of the uncontrolled pedestrian crossing
- Vehicles cannot change lanes in the zig-zag zone

FLORIDA PEDESTRIAN SAFETY PLAN
Issue #4: Mid-block Crossings

Florida Department of Transportation, Safety Office; February 1992

- Successful means to reduce auto/pedestrian crashes
  - responds to human needs and practices
  - can improve sight distances
  - reduces conflict points

- Mid-block crossings are applicable when all of the following conditions are present:
  - high pedestrian concentrations
  - mid-block crossing provides the most direct route
  - mid-block crossing presents the least conflict with vehicles

- Consider mid-block crossings when
  - land use encourages mid-block crossing
  - safety and capacity at adjacent intersections create dangerous crossing situations
  - spacing between adjacent signals exceeds 600 feet
  - capacity of roadway will not be seriously impeded by mid-block crossing
  - lesser measures to encourage pedestrians to cross at intersections have failed

- When properly designed and placed, mid-block crossings may be one of the least expensive safety improvements for pedestrians

- Most successful where traffic speeds are controlled (i.e., school zones, commercial zones)

- Four types of mid-block crossings

  - **PEDESTRIAN REFUGE:** continuous or short length raised median; helps pedestrians cross by separating traffic streams; pedestrians can accept smaller gaps from each direction; pedestrians take responsibility for their lives and don't assume cars will stop (at signals, cars can/do run red lights and hit peds)

  - **MID-BLOCK FLARE** (BULBOUT): shortens pedestrian crossing distances and increases pedestrian visibility and height to motorists; typically used where vehicle capacity is not a concern; works best on roadways with on-street parking

  - **PEDESTRIAN CROSSINGS:** special emphasis crosswalk can be used where there are adequate sight distances for drivers and pedestrians of each other; should be lit at night if used at night

  - **SIGNALIZED CROSSINGS:** can be used if MUTCD warrants 4C-5 are met, but consider using a refuge before doing so; refuge may not be appropriate with high traffic volumes, narrow roadway, or existence of special pedestrian needs

PEDESTRIAN WARNING FLASHERS

Sparks and Cynecki, "Pedestrian Warning Flashers in an Urban Environment: Do They Help?" ITE Journal, January 1990.

- Flashing beacons are frequently requested by citizens who believe their use will reduce vehicle speeds and improve safety.

- Flashing beacons serve a useful purpose when used to alert drivers unfamiliar with the area to unexpected conditions (i.e., a sharp curve on a rural road).

- There is currently little evidence that flashing warning beacons are effective when used to warn of intermittent concerns, such as the presence of pedestrians in an urban environment. [This conclusion is based primarily on school zone research.]

- Arizona Dept. of Transportation has not found flashers useful for intermittent conditions such as pedestrian crossing locations.

  - "They simply cease to command respect of the drivers."

  - The use of flashers is all too often an emotional response to symptoms of a lack of pedestrian safety education, not a traffic engineering problem.

Todd, Kenneth "Pedestrian Regulations in the United States: A Critical Review", Transportation Quarterly, October 1992.

- If the safest time to cross a street is the moment when vehicles are so far away that there can be no conflict, the safest location to cross is a point where the pedestrian can concentrate on one conflict at a time and detect vehicles from a safe distance. The most hazardous location is a point where vehicles arrive from several directions and come into the pedestrian's field of vision only at the last moment.

- Refuges allow pedestrians to cross in two stages, concentrate on vehicles from one direction at a time, and wait while trapped in traffic. They reduce delay substantially. (Gerlough showed pedestrians took seven times longer to cross a two-way street without a refuge than with one; Smith et al. noted a delay ten times as long.)

- WALK ALERT program adopted by several Federal agencies: "Green lights, walk signals and crosswalks do not guarantee a safe crossing. Look left, right and left again. Look over your shoulder. Cross only when the way is clear. Keep looking as you cross.

MEDIANS AND REFUGE ISLANDS

Smith, "The Suburban Pedestrian Crossing Dilemma", TR News, January-February 1993.

- The transportation engineer is continually faced with the dilemma of how to allow for convenient and safe pedestrian crossings and maintain traffic capacity. The issues that make this problem particularly difficult include:

  - Traffic signals are much farther apart in suburban settings than they are in urban areas as a result of modern development patterns. Although pedestrians are advised to cross at the nearest signal, this is impractical along many suburban highways because of the distances between signalized intersections.

  - Pedestrian crossing locations are also more scattered than they are in urban areas as a result of the increased dispersion of land use activities.

  - Arterial streets in suburban areas are typically wider, making crossing them more difficult.

  - Pedestrians are often hard to see along arterial streets at night because of headlight glare and lower levels of lighting. Of the approximately 8,000 pedestrian fatalities, about half take place at night.

- Medians (raised or flush) can add significantly to pedestrian mobility and safety on multi-lane highways in suburban areas.

  - Medians greatly simplify the pedestrian's task of crossing the street without adversely affecting arterial traffic flow, as would occur with traffic signal installations.

  - The ability to segment the crossing into two simpler parts reduces the delay to the pedestrian and increases the safety of the crossing.

- Although channelization islands are a common treatment used to separate traffic movements at intersections, mid-block refuge islands are seldom considered as pedestrian treatments in the United States.

- Pedestrian refuge islands should be considered where there is a concentration of pedestrian crossing activity and a full median cannot be provided.

SYNTHESIS OF SAFETY RESEARCH - PEDESTRIANS
US DOT and FHWA sponsored document by Charles V. Zeeger, August 1991

CROSSWALKS

Crosswalk Location and Marking

- Marked and signed crossings are widely employed as a means of reducing pedestrian hazard when crossing a street. Recent evidence indicates these do not guarantee reduced risk and must be applied with care.
- In general, marked crosswalks have the following advantages:
  - Help orient pedestrians in finding their way across complex intersections.
  - Help show pedestrians the shortest route across traffic with the least exposure to vehicular traffic and traffic conflicts.
  - Help position pedestrians where they can be seen best by oncoming traffic.
  - Help utilize the presence of illumination to improve pedestrian safety at night.
  - Help channel and limit pedestrian traffic to specific locations thus aiding enforcement of pedestrian crossing regulations.
  - Act as a warning device and reminder to motorists of locations where pedestrian conflicts can be expected.
- In general, marked crosswalks have the following disadvantages:
  - Cause some pedestrians to have a false sense of security, which would place them in a hazardous position with respect to vehicular traffic.
  - Cause the pedestrian to think the motorist can and will stop in all cases, even when it is impossible to do so.
  - Cause a greater number of rear end and associated collisions due to pedestrians not waiting for gaps in traffic.
  - Cause an increase in fatal and serious injury accidents.
  - Cause an increase in community-wide accident insurance rates.
  - Cause disrespect for all pedestrian regulations and traffic controls.
- Knoblach et al. recommend that crosswalk markings be installed under the following conditions:
  - At all signalized intersections which have pedestrian signal heads.
  - At all locations with a school crossing guard who is normally available to assist children across the street.
  - At all intersections and mid-block crossing locations which satisfy the minimum volume criteria in Figure 16 for pedestrians and vehicular traffic. To satisfy this criteria, a marked crosswalk is warranted if the basic criteria for sight distance and speed limit are met, and the pedestrian and vehicular volume are high enough to place the location above the appropriate curve in the figure. Each approach leg is analyzed separately, so a crosswalk may be warranted on one or both sides of an intersection.
  - At other locations with a need to clarify the preferred crossing location when pedestrian confusion may otherwise exist.

Alternative Crossing Treatments

- Innovative approaches to pedestrian crossing protection were tested in Detroit, MI. Combinations of signing, marking, lighting, and pedestrian signal actuation were installed. The alternative configurations included overhead signs with internal illumination, flashing beacons, and pedestrian signals.
  - There was a significantly greater relative use of crosswalks, primarily during daylight hours, following installation of devices.
  - The speed distribution of unencumbered vehicles in the vicinity of the crosswalk did not respond substantially to the installations.
  - Many more drivers slowed for pedestrians waiting to cross the street.
  - Increased pedestrian usage of push buttons occurred, but not to the level expected.
  - Interviews with drivers and pedestrians showed:
    - Pedestrians expected drivers to slow down when the device was activated
    - Drivers did not expect to have to stop or slow down significantly unless a traffic signal or stop sign was in use.

- Canada conducted a study of special crosswalks in use in five of its major cities. The best system in terms of performance rating per unit cost was in Toronto. The Toronto system consisted of pavement markings and roadside signs. Large "X's" were marked on the pavement in each lane 100 ft back on the approach to the crosswalk. The stripe widths were between 12 and 20 inches, and the "X" was 20 ft long. A standard advanced pedestrian crossing warning sign was mounted adjacent to the "X" at the roadside. The crosswalk was marked no less than 8 ft wide with two 6 - 8 inch stripes, 88 inches apart, delineating each side of the crosswalk.
  - Before and after studies showed a marked decline in pedestrian fatalities.
  - Two hazardous behavior patterns were noted:
    - Some pedestrians would step off the curb without signaling their intention to cross the roadway.
    - Some vehicles passed each other just before the crosswalk.

DRIVER AND PEDESTRIAN CHARACTERISTICS

Traffic Engineering Handbook, 4th Ed., Institute of Transportation Engineers, 1992, Chapter 1.

- Pedestrians will typically not walk more than a mile to work or half a mile to catch a bus, and 80% of their distances traveled will be less than 3,000 ft.

- Peak pedestrian travel times are around noon, about double the average volume at the morning and afternoon rush hours.

- Pedestrians often consider themselves outside the law, and enforcement typically is low.

- Walking speeds used for design purposes assume free flow with plenty of space for pedestrians to choose their own speeds (however, speed drops as density increases). Although it is often assumed for engineering design purposes that walking speeds are 4 ft/sec, many (especially the elderly) walk much slower. Six levels of service for pedestrian traffic have been identified, based on the number of square feet per person.
  - Estimates by the ITE suggest that the mean walking speed is 3.7 ft/sec and that 35% of pedestrians walk more slowly than the 4-sec design standard.
  - Walking speeds would likely be slowed even more under winter conditions with snow and heavy footwear.
  - Among the factors that influence walking speed are density, gender, and size of the group. Speed is reduced in higher-density conditions and when pedestrians walk in pairs as compared to alone.

- Accident data have shown that the proportion of accidents associated with left-turning vehicles is nearly double that for right-turning vehicles at intersections of two one-way streets. In comparison with through maneuvers, the likelihood of a pedestrian accident during left-turning maneuvers is about four times as great.

- Traffic control measures to reduce pedestrian-vehicle conflicts will increase delays for both pedestrian and vehicular traffic. The engineer is thus in a conflict between providing safety and generating operational efficiency.

- Pedestrian signals with concurrent timing might not be effective for these reasons:
  - Compliance with pedestrian signals is generally poor, with violation rates of the DON'T WALK signal being higher than 50% in most cities.
  - The presence of a pedestrian signal may create a false sense of security, leaving pedestrians with the impression that they are fully protected.
  - The use of flashing DON'T WALK for clearance intervals is not well understood, nor is the use of the flashing WALK to indicate turning vehicles.
  - Pedestrians tend not to use pedestrian-actuated signals.
  - There is a lack of uniformity in the use of pedestrian signals across cities.

- A threshold value of clearance interval exists beyond which pedestrians will ignore the signal and accept natural gaps in the traffic to cross.

- Night time conditions are perhaps the most hazardous for pedestrians. Pedestrians are more difficult for drivers to detect and pedestrians typically overestimate the distance at which they can be seen by approximately twice the range. In addition, clothing with low reflectivity is often worn.

- The handicapped pedestrian includes not just those with physical problems such as restricted mobility or perception, but also those temporarily disabled because they are encumbered by carrying luggage, packages, children, etc.

- The behavior of child pedestrians is different in a number of important ways from that of adults. The child's conception of safety is poorly formulated and his or her schema for critical behaviors such as crossing the street is not well developed.

- The following factors appear to contribute to the child pedestrian problem:
    - Their small stature makes it difficult for them to evaluate the traffic situation correctly.
    - They have difficulty distributing their attention, and they are therefore easily preoccupied or distracted in hazardous traffic situations.
    - They have difficulty discriminating right from lift.
    - They have difficulty in correctly perceiving the direction of sound and the speed of vehicles.
    - Many youngsters believe that the safest way to cross the street is to run.
    - Many children believe it is safe to cross against the red light.
    - Children have a poor understanding of the use of traffic control devices and crosswalks.

- Being a pedestrian can be a hazardous activity for the elderly for a number of reasons, including limited vision and hearing, slower reaction time, reduced walking speed, and prejudice on the part of drivers toward older pedestrians.

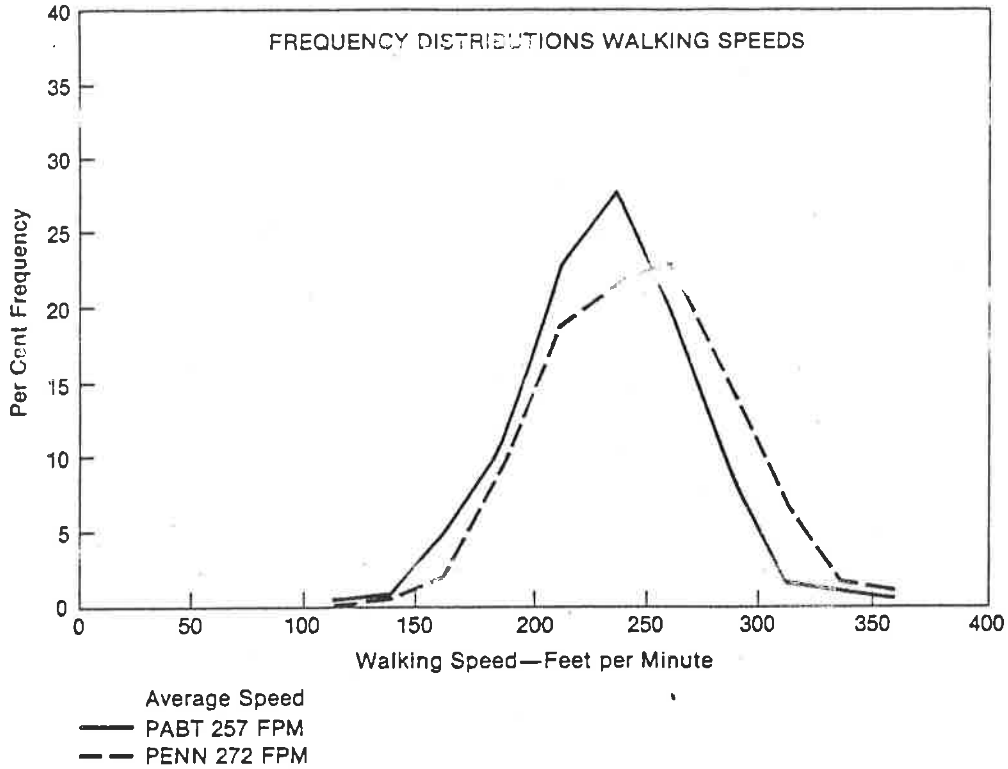


Figure 1–9. Pedestrian walking speeds—unimpeded free-flow.
SOURCE: J.J. FRUIN, *Pedestrian Planning and Design*, revised edition, Mobile, Alabama: ELEVATOR WORLD, INC. (1987), p. 40.

the location of the turn, the angle between these increases, resulting in less time to look at the crosswalk for pedestrians.

Possible solutions to this problem include modification of vehicle design (narrower A-pillars, more efficient windshield wipers), environmental changes (placement of an additional signal at the far left side of the intersection, so that both the crosswalk and the signal would be within easy view with minimal eye movement on the part of the driver), education of drivers and pedestrians to increase awareness of the issue, and recommending slower turning speeds to drivers.

The merits of using pavement markings at pedestrian crosswalks are unclear. Research done in Europe indicates that they do have safety benefits. However, a large U.S. study based on five years' worth of data at 400 intersections (each with one painted and one unpainted crosswalk) found that pedestrian accident rates were about twice as great at marked, as opposed to unmarked, crosswalks.[83]

There is clearly a need to record accidents in terms of some index of exposure to risk. One of the few studies in which this was done used an index based on the sum of the products of conflicting pedestrian-vehicle flows.[84] It showed that marked crosswalks are much safer than unmarked ones.

[83] B.F. Herms, "Pedestrian Crosswalk Study: Accidents in Painted and Unpainted Crosswalks," *Highway Research Record*, 406 (1972), 1–13.

[84] R. Knoblauch, "Urban Pedestrian Accident Countermeasures Experimental Evaluation: Vol. 2, Accident Studies," U.S. Dept. of Transportation Final Report DOT HS-801-347 (February 1975).

It has been suggested that markings could aid elderly pedestrians by keeping them walking straight across the street rather than at an angle.

Pedestrian signals

The need for traffic signals to control pedestrian movement seems apparent. Traffic-control measures to reduce pedestrian-vehicle conflicts will, of course, increase delays for both pedestrian and vehicular traffic. The engineer is thus in a conflict between providing safety and generating operational efficiency.

The basic types of pedestrian signal timing are:

1. *concurrent (standard)*, where pedestrians walk concurrently with vehicle traffic
2. *early release*, where pedestrians leave the curb before traffic is allowed to turn
3. *late release*, where pedestrians must wait a portion of the green phase while traffic turns left
4. *exclusive*, where pedestrians have a protected crossing interval (scramble timing allows pedestrians to cross the intersection diagonally).

In spite of the numerous research reports on pedestrian signals, there is a good deal we do not know about their effects on safety. Some studies examined too few intersections, or too few accidents to draw meaningful conclusions. The use of several years' data is recommended. Some studies

PEDESTRIAN STUDIES

Pignataro, Traffic Engineering Theory and Practice, 1973, Chapter 15.

- Adequate pedestrian gap time is given by the equation:

  $G = W/3.5 + 3 + (N - 1)*2$

  where, G = adequate time gap, in seconds
  W = width of pavement to be crossed, in feet
  3.5 = assumed walking speed, in feet per second
  3 = pedestrian reaction time, in seconds
  N = number of rows of 5 pedestrians across to be crossed
  2 = spacing between rows, in seconds

- Gaps must be measured considering all lanes and directions of traffic

- The actual delay to pedestrians is also a useful value in analyzing the control situation. At unsignalized locations, this may be estimated by measuring gaps in the traffic stream, and considering the percentage of time during which a gap of at least G is available.

  $D = (T - t)/T$

  where, D = percentage of time that 85th percentile pedestrian group cannot safely cross
  T = total study time, in seconds
  t = total of all gaps greater than or equal to G, in seconds

- Pedestrians alter their speed depending upon the closeness of vehicles when crossing the street. Mean walking speeds varied from 6.4 ft/sec when the gap before the arrival of the next car was 2 seconds to 3.8 ft/sec when the gap was 9 seconds or more.

TABLE 15-2. PEDESTRIAN WALKING SPEEDS AT MID-BLOCK AND INTERSECTION LOCATIONS (fps)

	MID-BLOCK	*INTERSECTION*
Men	4.93	4.93
Women	4.63	4.53
All	4.80	4.72

(Source: Hoel, "Pedestrian Travel Rates in Central Business Districts," in *TE*, January, 1968)

TABLE 15-3. LEVEL OF SERVICE STANDARDS FOR QUEUED PEDESTRIANS

LEVEL OF SERVICE	*PEDESTRIAN MODULE* (ft^2)	*INTERPERSON SPACING (ft)*	*CIRCULATION THROUGH QUEUE*
A	More Than 13	4	Unrestricted
B	10–13	3½–4	Slightly Restricted
C	7–10	3–3½	Restricted, but Possible By Disturbing Others
D	3–7	2–3	Severely Restricted
E	2–3	2	Not Possible
F	Less Than 2	—	Not Possible

(Source: Fruin, *Designing for Pedestrians, A Level of Service Concept.* Dissertation, Polytechnic Institute of Brooklyn, January, 1970, Table 9-1)

TABLE 15-4. LEVEL OF SERVICE STANDARDS FOR PEDESTRIAN WALKWAYS

LEVEL OF SERVICE	*PEDESTRIAN MODULE* (ft^2)	*PEDESTRIAN VOLUME (ppm/ft)*	*NORMAL FLOW**	*REVERSE FLOW***	*CROSS FLOW†*
A	More Than 35	7	F	F	F
B	25–35	7–10	F	F	R
C	15–25	10–15	F	R	R
D	10–15	15–20	R	R	S
E	5–10	20–25	R	S	S
F	Less Than 5	Variable up to 25	S	S	S

PPM/FT = Persons per minute per foot width of walkway
F = relatively free, minimum of restrictions or inconvenience
R = restricted, higher probabilities of conflict and inconvenience
S = severely restricted
(Source: Fruin, *Designing for Pedestrians, A Level of Service Concept.* Dissertation, Polytechnic Institute of Brooklyn, January, 1970, Table 5-4)
* Direction of major flow.
** Opposite direction to major flow.
† Direction at right angles to major flow.

TABLE 15-5. APPROXIMATE TIME PER PASSENGER, LOADING HEADWAY BASED ON FARE COLLECTION

FARE	*SECONDS*
Single Coin, or Token Fare Box, or Pass	2–3
Odd-Penny Cash Fares	3–4
Multiple-Zone Fares	
Prepurchased Tickets	4–6
Cash	6–8

(Source: *Traffic Engineering Handbook*, ITE, 1965, Table 13-7)

TABLE 15-6. REQUIRED NUMBER OF BUS LOADING STALLS

PASSENGER LOADING TIME (sec)		3			5			7		
Passengers Per Bus		30	45	60	30	45	60	30	45	60
Scheduled Bus Headway (min)	2	1	2	2	2	2	3	2	3	3
	5	1	1	1	1	1	1	1	2	2
	10	1	1	1	1	1	1	1	1	1

(Source: *Traffic Engineering Handbook*, ITE, 1965, Table 13-8)

CROSSWALKS

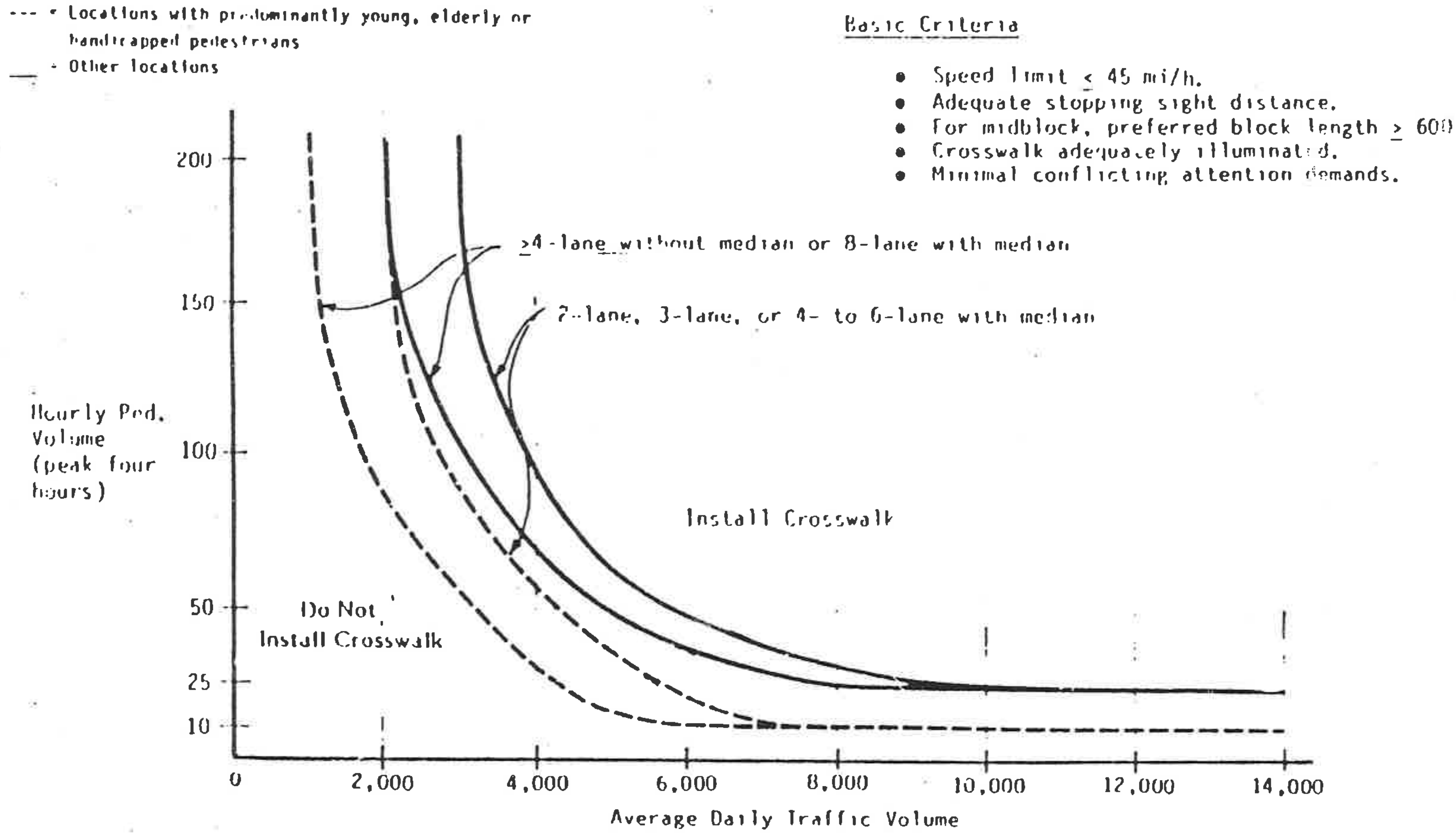
Investigation of Exposure Based Pedestrian Accident Areas: Crosswalks, Sidewalks, Local Streets and Major Arterials, FHWA/RD-88/038, September 1988.

Recommended guidelines for crosswalk markings:

- Crosswalks should not be marked where crossing the street may be unusually dangerous (i.e., locations with high traffic speeds, poor sight distance, or poor illumination).
- In light of the installation and maintenance costs of pavement markings, crosswalk markings should be located at places expected to receive sufficient benefit. This suggests that crosswalks with low vehicular volume and/or low pedestrian volume do not warrant markings. The determination of minimum pedestrian and vehicle volume thresholds are an important part of establishing reasonable guidelines for installation of crosswalk markings.
- Guideline for installing crosswalks should include the type of pedestrians expected to be crossing the street. Lower volume thresholds should be considered for areas where there is a greater proportion of less experienced and less agile pedestrians (i.e., near schools and/or elderly housing areas).
- Crosswalk markings in higher-risk crossing areas (higher traffic volumes and speeds) should be supplemented by advance warning signs and, in some cases, advance warning pavement markings.
- Crosswalks should be used selectively. Allowing a proliferation of crosswalks reduces the overall effectiveness of each crosswalk.
- Specific variables that should be considered when locating crosswalks include: activities located nearby (i.e., schools, shopping), pedestrian volume, vehicular volume, sight distance, vehicular speeds, street width and presence of a median, one-way versus two-way operation, and geometrics of the highway or intersection being crossed.

Crosswalk markings should be installed at:

- All signalized intersections with pedestrian signal heads.
- All locations where a school crossing guard is normally stationed to assist children in crossing the street.
- All intersections and mid-block crossings satisfying the minimum vehicular and pedestrian volume criteria in Figure 9. As long as the basic criteria governing sight distance, speed limit, etc., are met, a crosswalk is deemed appropriate if the pedestrian and vehicular volumes place it above the appropriate curve in Figure 9. Each crosswalk is analyzed by approach leg, indicating that a crosswalk might be warranted on one side of an intersection and not the other. Thus, the guidelines might suggest that only one crosswalk need be marked at a given intersection. If each approach warranted a crosswalk, then all would be marked.
- All other locations where there is a need to clarify the preferred crossing location when the proper location for crossing would otherwise be confusing.



1. If using only the peak hour, threshold must be increased by 1.5
2. For streets with a median, use one-way (directional) ADT volume.

Other notes: Minimum striping is 6" parallel lines. Consider bolder markings and/or supplementary advance markings or signing at uncontrolled locations where speed limits exceed 35 mi/h.

Figure 9. Guidelines for crosswalk installation at uncontrolled intersection legs, midblock crossings, and signalized intersections without ped heads.

BIBLIOGRAPHY

Dunn, Roger C.M., *"Unsignalized Pedestrian Crossings: New Zealand's Technical Recommendation."* ITE Journal; September 1989.

Florida Pedestrian Safety Plan. Florida Department of Transportation, Safety Office; February 1982.

Henderson, D.M., and L.A. Ross, *"Development of the Pedestrian Crossover as a Traffic Control Device in the Regional Municipality of Ottawa-Carleton."* RTAC Forum, Vol. 2, No. 1.; (date unknown).

Hensen, Ronald J., *Mid-block Signal Operations in Los Angeles."* Phone conversation with John Fisher (Los Angeles Department of Transportation); June 28, 1993.

Investigation of Exposure Based Pedestrian Accident Areas: Crosswalks, Sidewalks, Local Streets and Major Arterials. U.S. Department of Transportation, Federal Highway Administration, Report No. FHWA/RD-88/038; September 1988.

King, G.F., *"Pedestrian Delay and Pedestrian Signal Warrants."* Transportation Research Record No. 629, Transportation Research Board; 1977.

Manual on Uniform Traffic Control Devices for Streets and Highways. U.S. Department of Transportation, Federal Highway Administration; 1988

Pedestrian Signalization Alternatives. U.S. Department of Transportation, Federal Highway Administration, Report No. FHWA/RD-83/102; July 1985.

Pignataro, Louis J., *Traffic Engineering Theory and Practice*. Prentice-Hall; 1973.

Reiss, Martin L., *"Knowledge and Perceptions of Young Pedestrians."* Transportation Research Record No. 629, Transportation Research Board; 1977.

Ribbens, H., *"Evaluation of the Proposed Guidelines for Uncontrolled Mid-Block Pedestrian Crossings."* National Institute for Transport and Road Research, South Africa; October 1985.

Ribbens, H. and G. Brafman Bahar, *"Proposed Warrants for South African Mid-Block Pedestrian Crossings."* National Institute for Transport and Road Research, South Africa; October 1982.

Smith, Steven A., *"The Suburban Pedestrian Crossing Dilemma."* TR News; January-February 1993.

Sparks, James W. and Michael J. Cynecki, *"Pedestrian Warning Flashers in an Urban Environment: Do They Help?"* ITE Journal; January 1990.

Traffic Engineering Handbook, 4th Edition. Institute of Transportation Engineers; 1992.

Todd, Kenneth, *"Pedestrian Regulations in the United States: A Critical Review."* Transportation Quarterly; October 1992.

Zeeger, Charles V., *Synthesis of Safety Research - Pedestrians*. U.S. Department of Transportation, Federal Highway Administration, Report No. FHWA-SA-91-034; August 1991.