# PEDESTRIAN SIGNALIZATION ALTERNATIVES

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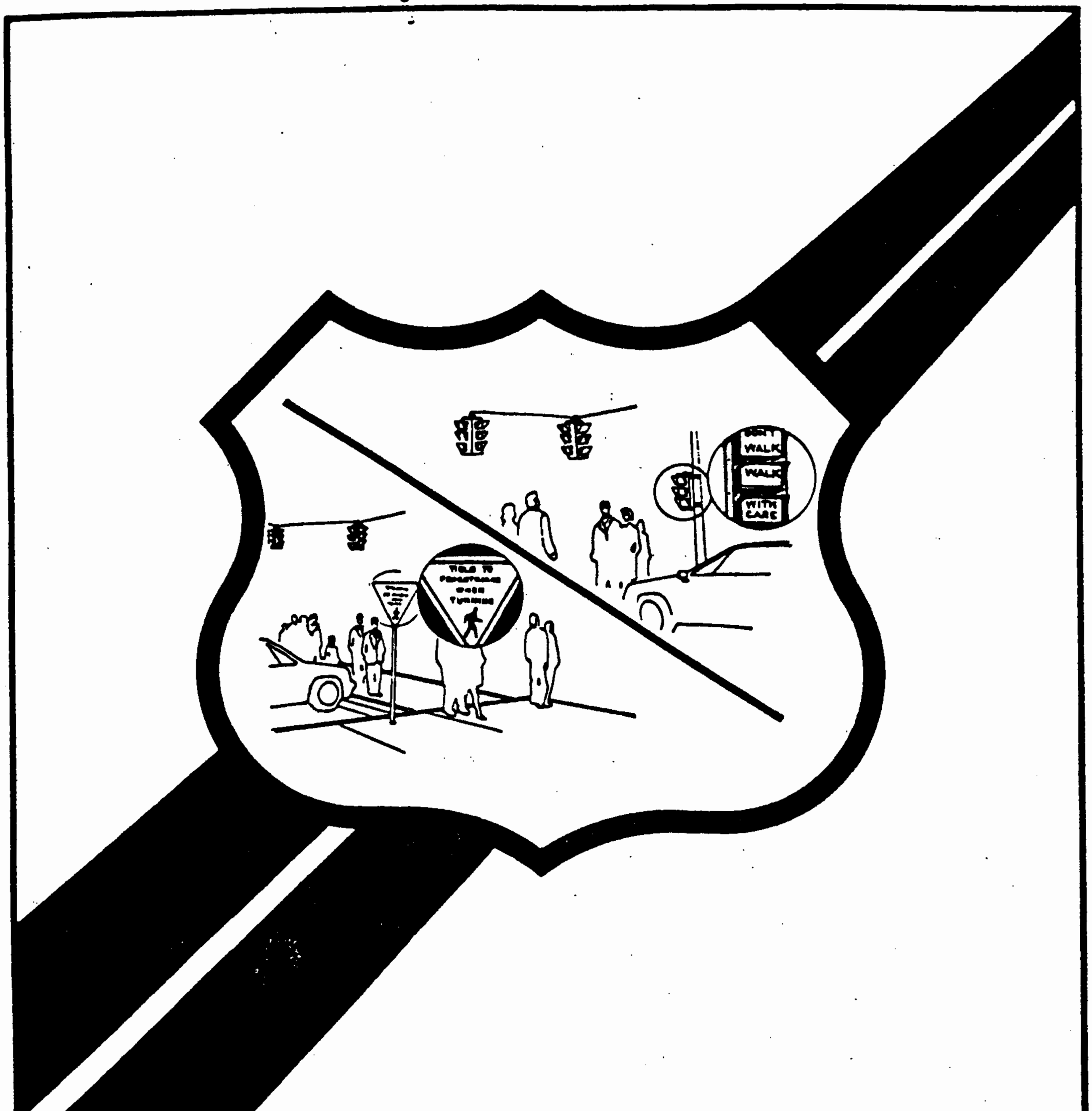

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16. Abstract


The purpose of this study was to determine the operational and safety effects of various pedestrian signalization alternatives. An analysis was conducted of pedestrian accidents, traffic and pedestrian volumes, geometrics, and signal data for 1,297 signalized intersections in 15 U.S. cities to determine the safety effects of pedestrian signals and signal timing. The presence of standard-timed pedestrian (WALK/DONT WALK) signals was found to have no significant effect on pedestrian accidents. However, scramble (or exclusive) pedestrian timing was associated with significantly lower pedestrian accidents. Current MUTCD warrants for pedestrian signals were evaluated and Warrant 3 (Minimum Pedestrian Warrant) was found to be ineffective. An improved warrant was developed and is recommended for adoption.

Several new sign and signal alternatives were developed and field tested to indicate the clearance interval and to warn of pedestrian-vehicle conflicts. The alternatives recommended for inclusion in the MUTCD at high pedestrian hazard intersections include the WALK WITH CARE signal, a YIELD TO PEDESTRIANS WHEN TURNING regulatory sign, a PEDESTRIANS WATCH FOR TURNING VEHICLES warning sign, and a pedestrian signal explanation sign (word and symbolic). A three-phase pedestrian signal using DONT START to indicate the clearance interval was recommended for additional testing, and little or no benefit was found from the flashing WALK or the steady DONT WALK. Allowing pedestrians to yield to traffic and cross against the pedestrian signal was found to be undesirable based on safety considerations.

The Appendixes are available upon request from the Federal Highway Administration.


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# INTRODUCTION

In recent years, safety research has uncovered numerous problems regarding current pedestrian signalization practices. The lack of uniformity in pedestrian signal devices and timing strategies is thought by many to contribute to the ineffectiveness of the signals in achieving improved pedestrian safety. Further, it is recognized that there is considerable confusion and misunderstanding regarding the meaning of the flashing DONT WALK indication (or flashing hand) for the clearance interval and the flashing WALK indication (or flashing man) to warn pedestrians of turning vehicles.

Testing of new types of pedestrian signal devices has been conducted in recent years in an attempt to improve pedestrian safety. One of the most notable studies was conducted in 1977 for the Federal Highway Administration, which involved several aspects including a study of timing for pedestrian signals and the development and testing of pedestrian signal displays. One of the major findings in that study led to the recommended use of the symbolic (hand and walking man) displays that are currently in use in many cities [1].

While numerous other findings resulted from that study and others, many important issues remain unresolved relative to pedestrian signals. Five of these major issues are:

1. What is the effect of pedestrian signal indications (WALK/DONT WALK or symbolic signals) and signal timing on pedestrian safety?

2. Are the Manual on Uniform Traffic Control Devices (MUTCD) pedestrian-related signal warrants appropriate, or if not, what new warrants should be used?

3. What are other feasible alternatives to the pedestrian clearance interval (in place of the flashing DONT WALK) that would result in better pedestrian understanding and improved compliance and safety?

4. Are other feasible alternatives available to warn pedestrians about the potential for conflicts with turning vehicles instead of the flashing WALK indication?

5. At intersections where gaps exist in traffic flow, should pedestrians be provided with a pedestrian "yield" signal to allow them to legally cross the street when clear?

These five basic questions are addressed in the following chapters. Chapter I involves an analysis of pedestrian signals and timing on safety. Chapter II is an evaluation of warrants relative to pedestrian signals and presents a recommended alternate warrant. Chapter III summarizes the results of field evaluations of several sign and signal devices relative to the pedestrian clearance interval and the potential for pedestrian conflicts with turning vehicles. Chapter IV is an investigation of the pedestrian yield concept. A summary of conclusions and recommendations is given in Chapter V.

# CHAPTER I - THE EFFECT OF PEDESTRIAN SIGNALS ON PEDESTRIAN ACCIDENTS

The purpose of this phase of the study was to determine the effects of pedestrian signal devices and signal timing strategies on pedestrian safety. A two pronged approach was utilized which involved an in-depth analysis of past efforts through a literature review and a detailed analysis of actual accident experience at a large sample of urban intersections. This approach was believed to be the most effective means to address the problems cited above.

Although many problems have been attributed to the current use of pedestrian signals, a comprehensive literature review failed to find any study which adequately quantified the effect of pedestrian signals on pedestrian accidents. It is important to understand the effect of pedestrian signals on safety to determine whether the continued use of pedestrian signals is justified on a safety basis, and whether changes are needed in their design and deployment. The literature did provide useful insights in this regard.

Since there are several signal timing options in practice in the U.S., one essential element of this study was the evaluation of the impact of these timing schemes on pedestrian safety. Pedestrian signal timing schemes include [1]:

- No Pedestrian Signal - Traffic signals exist without special pedestrian (WALK/DONT WALK) signals.
- Concurrent (Standard) - Allows pedestrians to walk concurrently with the movement of traffic.
- Early Release - Allows pedestrians to leave the curb before vehicles are permitted to turn.
- Late Release - Holds pedestrians (with respect to vehicles) until a certain portion of the phase has been given to turning vehicles.
- Exclusive - Traffic is held on all approaches to allow pedestrians to cross any street. Scramble (or Barnes dance) timing is a form of exclusive timing which also allows for diagonal crossings.
- Others - Variations of the above where pedestrians are given different indications on parallel crosswalks to protect them during special traffic phases (i.e., special left-turn phases, split phasing, etc.).

To assess the impact of these signal timing schemes, a sample of signalized intersection sites was selected. The sample included sites without pedestrian signals (termed no signal in the report) as well as sites with the various signal timing schemes defined above. A detailed analysis of the accident experience at these sites was conducted to: (1) identify the types of intersections or situations where pedestrian signals are most (or least) desirable from a safety standpoint, and (2) aid in determining whether changes are needed in the design of pedestrian signals to improve their effectiveness. Such information is critical to the traffic engineering community which is responsible for the installation and timing of pedestrian signals.

## Background

Although considerable research has been conducted in recent years regarding pedestrian safety, few articles and publications deal specifically with the issue of pedestrian signals and safety. Fleig and Duffy found no significant reduction in the proportion of unsafe acts or pedestrian accidents after the installation of scramble-timed pedestrian signals at eleven locations [2]. Their accident data was limited, however, to 27 accidents in the before period and 25 accidents in the after period with each of these periods only one year in duration. The authors concluded that pedestrian signals are not effective in reducing pedestrian accidents, but the limited data used raises questions about the statistical validity of this conclusion.

Several studies have been conducted concerning the effect of pedestrian signals on pedestrian compliance and behavior, which are sometimes considered to be indirect measures of pedestrian safety. In a 1977 study, Abrams and Smith concluded that compared to standard timing, ... early release timing significantly increases vehicle delay without reducing pedestrian delay and late release timing increases overall intersection delay at most volume levels but does not adversely affect pedestrian compliance rates [3]. Scramble timing was found to be associated with higher violation rates [3]. Mortimer conducted a study in 1973 to test compliance rates at pedestrian crossings with and without pedestrian signals [4]. He found better signal compliance rates and fewer serious pedestrian-vehicle conflicts at intersections with pedestrian signals than at those without them.

Several other studies have been conducted outside the U.S. regarding the effect of pedestrian signals on safety. A 1979 study by Inwood and Grayson in England found that the push-button type of pedestrian signals (termed Pelican crossings) are no more effective than locations with black and white striped crosswalks and flashing beacons (termed Zebra crossings) in reducing pedestrian accidents [5]. However, a study by Williams in Australia reported that accidents dropped by 60 percent at a group of locations when pedestrian actuated signals were installed at former Zebra crossings [6]. The precise effect of each of these countermeasures was not determined. A detailed summary of the findings of the literature review relative to pedestrian signals is provided in Appendix A.

Many studies conducted in the U.S. and abroad have utilized measures of effectiveness (MOE's) such as pedestrian compliance or conflicts as a measure of pedestrian safety. However, there is not yet a clearly established relationship between pedestrian accidents and such "surrogate" measures. While these past studies provided useful insights into the issue, it was concluded that they did not provide sufficient information to establish the safety benefits of pedestrian signals. It was, therefore, decided that a more comprehensive analysis was warranted which would utilize several years of pedestrian accident data at a large number of urban and suburban intersections. The research methodology, study results, summary and conclusions, and recommendations are presented in the following sections.

## Methodology

To properly assess the true effects of pedestrian signals and timing on pedestrian safety, a carefully conceived methodology was required. The methodology established for this project consisted of four steps, which included: preparing an analysis plan, establishing data needs, selecting data collection sites, and collecting and analyzing data. Each of these steps is described below.

### Analysis Plan

The evaluation approach selected for this research involved the use of pedestrian accident experience, instead of pedestrian behavior, compliance measures, or other accident surrogates to determine the effect of pedestrian signals and timing on pedestrian safety. The two types of accident analysis considered were: (1) the analysis of pedestrian accidents before and after installation of a pedestrian signal; and (2) a comparative analysis of accidents at locations with and without pedestrian signals. Before and after analyses can be used to determine cause-and-effect relationships, preferably using control sites and looking at accident trends over time in order to minimize the common threats to evaluation validity (i.e., regression-to-the-mean, changes in accident trends over time, compounding effects of other locational factors, and data instability). However, this analysis approach was rejected due to: (1) the small number of accidents per site; (2) the difficulty in finding suitable test sites (with several years of accident data before and after the installation of a pedestrian signal) and control sites; and (3) the problem with isolating the effect of the pedestrian signals from other locational features.

The comparative analysis approach involves selecting a large sample of sites with and without pedestrian signals and representing various timing schemes. Intersections having similar geometric or operational features are grouped together and accident data are compared for each group. This approach usually allows for the creation of a large data base without relying on sites where pedestrian signals have been added in recent years. The possible disadvantages with a comparative analysis are that no two intersections are exactly alike, so a large number of traffic, geometric and operational data variables are needed for each site to help isolate differences and insure reliability of results. A comparative analysis does not show cause and effect relationships, but does allow for determining relationships between variables, if the proper statistical tests are used. A comparative analysis approach was subsequently selected for this study.

## Data Needs

The data needs were established based on the findings of the literature review and on the objectives of the study. Data were needed to assess pedestrian accident experience and to characterize intersection locations to permit the isolation of influencing factors. The basic analysis approach was designed to compare the pedestrian accident experience between signalized locations with and without pedestrian signals. Since a variety of signal timing schemes are used for pedestrian signals, it was deemed important to individually assess the effect of the various schemes on pedestrian accidents.

Independent variables were defined for classifying each candidate intersection in terms of its design, operation, and environment. The prime requirement of such variables was that they logically represent different levels of opportunity for pedestrian accidents. Since it is commonly accepted that pedestrian accidents are directly related to traffic and/or pedestrian volumes, these two variables were considered to be of major importance. Therefore, traffic and pedestrian volume data were collected for each intersection by leg (if available) for periods corresponding to the available accident data.

Additional independent variables used to describe the intersection characteristics included:

- Design factors - number of lanes, intersection skewness, type of pedestrian signal, number of turn lanes, turn prohibitions, and street width.

- Environmental factors - city, land use, area type, and functional classifications.

- Operational factors - signal timing and phasing, provision for right-turn-on-red, bus operations, speed limits, one-way or two-way street operations, and parking.

Information was also obtained regarding whether the pedestrian signals displayed a word (WALK/DONT WALK) or symbolic (man/hand) message. However, only a small number of symbolic signals were found in the selected cities. Also, the symbolic signal sites had generally not been in operation for a sufficient time period (i.e., three to six years) to allow for a proper accident analysis.

Detailed information concerning each pedestrian accident represented the major dependent variable for this study. Copies of accident reports were obtained when available and reviewed before coding. Computerized accident files were used in two of the 15 cities, since the accident report forms were not readily available. All basic information about each accident, including who was at fault, the accident type, the severity, contributing circumstances, and twenty other accident details were entered into the data base. Also, details were obtained on the pedestrian action (i.e., running with signal, playing in road, etc.), accident severity (i.e., fatal, A-type injury, B-type injury, C-type injury, no injury and unknown injury), age of pedestrian, and other items, as described in Appendix B.

Accidents were included in the analysis only if they were within the influence of the intersection and thought to be related to a crossing maneuver at the signal. For example, highly unusual accidents such as victim falls from moving car, pedestrian is hit while standing on sidewalk, police officer directing traffic, etc., were not included.

The data analysis plan addressed the question of how many years of accident data would be necessary to provide sound statistical results. While the use of pedestrian accident data was determined to be the most desirable method of directly measuring the effectiveness of pedestrian signalization options, the relative infrequency of pedestrian accidents was recognized to create a problem in the statistical analysis of the data. A minimum sample size of 1,000 intersections with 3 to 6 years of accident data per site was estimated to be needed to insure statistical reliability.

When coding each pedestrian accident type, consideration was given to the use of the scheme noted in the FHWA Model Pedestrian Safety Program User's Manual in 1971, as given in Table 1 [8]. However, insufficient information was available from the 15 cities to utilize this accident type scheme. For example, a different accident report form was used in nearly every city, and many report forms did not provide sufficient details (i.e., adequate sketch or officer's description) of the circumstances of each accident. Thus, the distinction between a "turning vehicle conflict" and a "vehicle turn-merge with attention conflict" was not possible since it requires information on whether the driver was paying attention. In two cities (Washington, D.C. and Richmond, Virginia) the computer accident

Table 1. Urban pedestrian accident types and critical behavioral descriptors.*

**DART-OUT (FIRST HALF) (23%)**
Midblock (not at intersection).
Pedestrian sudden appearance and short time exposure (driver does not have time to react to avoid collision).
Pedestrian crossed less than halfway.

**DART-OUT (SECOND HALF) (9%)**
Same as above except pedestrian gets at least halfway across before being struck.

**MIDBLOCK DASH (7%)**
Midblock (not at intersection).
Pedestrian running but *not* sudden appearance or short time exposure as above.

**INTERSECTION DASH (12%)**
Intersection.
Short time exposure *or* running.
Same as *Dart-out* except it occurs at an intersection.

**VEHICLE TURN-MERGE WITH ATTENTION CONFLICT (4%)**
Intersection or vehicle merge location.
Vehicle turning or merging into traffic.
Driver is attending to auto traffic in one direction and collides with pedestrian located in a different direction than that of the driver's attention.

**TURNING VEHICLE (5%)**
Intersection or vehicle merge location.
Vehicle turning or merging into traffic.
Driver attention *not* documented.
Pedestrian not running.

**MULTIPLE THREAT (3%)**
One or more vehicles stop in traffic lane (e.g. Lane 1) for pedestrian.
Pedestrian is hit as he steps into next parallel *same direction* traffic lane (e.g. Lane 2) by a vehicle moving in the same direction as the vehicle that stopped.
Collision vehicle driver's vision of pedestrian obstructed by the stopped vehicle.

**BUS STOP RELATED (2%)**
At a bus stop.
Pedestrian steps out from in front of bus at a bus stop and is struck by vehicle moving in same direction as bus while passing bus.
Same as Multiple Threat except that stopped vehicle is a bus at a bus stop.

**VENDOR-ICE CREAM TRUCK (2%)**
Pedestrian struck while going to or from a vendor in a vehicle on the street.

**DISABLED VEHICLE RELATED (1%)**
Pedestrian struck while working on or next to a disabled vehicle.

**RESULT OF VEHICLE-VEHICLE CRASH (3%)**
Pedestrian hit by vehicle(s) as a result of a vehicle-vehicle collision.

**TRAPPED (1%)**
Signalized intersection.
Pedestrian hit when traffic light turned red (for pedestrian) and cross traffic vehicles started moving.

*Percentages indicated are from recent research studies of urban pedestrian accidents (Snyder & Knoblauch, 1971; Knoblauch, 1975).

Source: Reference 8.

listings were used, since several years of accident report forms were not readily available. Subsequently, pedestrian accident types were categorized as: vehicle going straight ahead, right-turn vehicle, left-turn vehicle, and other or unknown.

Site Selection

The selection of suitable sites for this study required that candidate cities first be chosen to satisfy the following criteria:

- Cities should be willing to cooperate in the study and provide necessary data.
- Pedestrian and traffic volume data should be available at a large number of locations from counts conducted within the past five years.
- Other required locational data (i.e., signal timing sheets, land use maps, bus maps, dates of when any major locational changes were made, etc.) should also be readily available.
- Accident data should be of high quality, and accidents should be referenced accurately to the proper location. Accident reporting levels should be relatively consistent.
- Candidate cities should cover a wide geographic range throughout the U.S. and represent a variety of types, densities, traffic laws, and pedestrian attitudes.
- Cities should have an adequate sample of different types of pedestrian signals and signal timing schemes.

Of the more than 70 U.S. cities contacted for use in the study, 15 were selected after determining that they substantially met the above criteria. The only city found with more than 20 intersections with exclusive-timed pedestrian signals was Denver, Colorado. A few exclusive-timed intersections were also found in New Haven, Connecticut; Waltham, Massachusetts; Washington, D.C.; Kansas City, Missouri; West Hartford, Connecticut; Richmond, Virginia; and Tampa, Florida.

Problems were also encountered in identifying sites having early or late release timing. Most engineers were of the opinion that after flows of either autos or pedestrians are initiated, it is difficult to interrupt them on the same phase. Hence, very little use of these timing schemes were found within the cities contacted. The resulting categories of pedestrian signal timing included: (1) no pedestrian signal; (2) concurrent timing; (3) exclusive (including scramble) timing; and (4) other timing schemes (i.e., split-phasing, early or late release, etc.).

Cities were selected from several geographic regions to eliminate unwanted biases in the accidents related to climate, driver attitudes, systemwide accident characteristics, areawide safety emphasis, and pedestrian characteristics. Furthermore, an attempt was made to avoid cities which were considered to be highly unusual in terms of pedestrian activity, attitudes, and behavior. Stratified random sampling was employed within each city to insure that a representative group of sites was selected. A total of 1,297 intersections were selected from 15 cities across the U.S. as summarized in Table 2.

Sites within each city were selected to create a sample of typical urban and suburban signalized intersections, i.e., having four approach legs without unusual features. Offset intersection approaches, multiple legged intersections, and traffic circles were not included. The locations were different to some degree in terms of:

- The use of pedestrian signal timing schemes (i.e., concurrent, no pedestrian signal, exclusive, etc.)
- The range of pedestrian volumes (i.e., about 50 to 50,000 pedestrians per day crossing all approaches) and traffic volumes (i.e., about 1,600 to 78,000 entering vehicles per day.)
- Land use (i.e., commercial, residential, recreational, etc.)
- A variety of other roadway features (i.e., number of lanes, turn prohibitions, right-turn-on-red restrictions, combinations of one-way and two-way streets, etc.)

## Data Collection

The data collection effort involved one or more visits to the selected cities. The data collection effort involved extracting traffic, accident, and roadway data from files, maps, and computer printouts. Copies were made of the data files (i.e., volume data, location diagrams, signal information, and police accident report forms) where possible to facilitate office checking. All coding was checked for accuracy prior to keypunching.

The data was then keypunched and verified (double punched) to reduce data entry errors. Eight different data cards were used to describe the intersection layout, site characteristics, traffic volumes, and accident experience, as indicated in Table 3. After the data were read into the computer and sorted by city and location, two checking programs were developed to assist in editing the data. The first program checked for missing cards, improper card sequencing, and for the proper number of pedestrian accident detail cards. All discrepancies detected in the data were flagged by the computer program.

Table 2. Summary of intersections from each city used in the study.

| City | Number of Locations | | | | | Accident Data Collection Period | Total Number Of Pedestrian Accidents |
|---|---|---|---|---|---|---|---|
| | No Ped. Signal | Concurrent Timing | Exclusive Timing | Other Timing | Total | | |
| Albany, NY | 9 | 0 | 0 | 0 | 9 | 1976-1980 | 17 |
| Chicago, IL | 112 | 112 | 0 | 12 | 236 | 1977-1980 | 635 |
| Columbus, OH | 1 | 46 | 0 | 3 | 47 | 1978-1980 | 54 |
| Denver, CO | 0 | 16 | 39 | 0 | 55 | 1978-1980 | 34 |
| Detroit, MI | 62 | 108 | 0 | 0 | 170 | 1978-1980 | 222 |
| Grand Rapids, MI | 7 | 9 | 0 | 0 | 16 | 1978-1980 | 10 |
| Kansas City, MO | 10 | 28 | 1 | 0 | 39 | 1978-1980 | 11 |
| New Haven, CT | 27 | 0 | 13 | 0 | 43 | 1977-1979 | 43 |
| Richmond, VA | 84 | 2 | 11 | 0 | 97 | 1978-1980 | 55 |
| Seattle, WA | 41 | 99 | 0 | 0 | 140 | 1974-1979 | 342 |
| Tampa, FL | 21 | 21 | 16 | 0 | 58 | 1977-1980 | 33 |
| Toledo, OH | 66 | 113 | 0 | 5 | 184 | 1976-1980 | 198 |
| Waltham, MA | 0 | 0 | 11 | 0 | 11 | 1977-1980 | 2 |
| Washington, DC | 68 | 104 | 10 | 5 | 187 | 1974-1979 | 425 |
| West Hartford, CT | 0 | 0 | 5 | 0 | 5 | 1976-1979 | 0 |
| Total (Percent) | 508 (39.2) | 658 (50.7) | 109 (8.4) | 22 (1.7) | 1,297 (100.0) | | 2,081 |

*Not all of the selected sites within each city were studied during the entire data collection period.

Table 3. Description of intersection data collected.

| Card Number | Type of Data | Data Elements |
|---|---|---|
| 1 | Location Descriptors | Contains information describing the location including street names, operation (i.e., one-way or two-way), land use, speed limits, angle between the intersecting streets, area type, and land use designations. |
| 2 | Signal Parameters | Describes the signal timing parameters, type of pedestrian signal hardware, and pedestrian signal timing schemes (standard, scramble, early release, etc.). |
| 3 | Vehicle Volumes | Provides the total approach volume, and left and right turning volumes for each intersection approach leg. |
| 4 | Volume Factors and Pedestrian Volumes | Contains information on the peak-hour vehicular volumes and pedestrian volumes as well as total pedestrian volumes by direction of travel. |
| 5 | Intersection Design Data | Data includes functional classification of each street, number of through and exclusive turn lanes, parking restrictions near the intersection, turning controls, and pavement widths. |
| 6 | Accident Totals | Contains the total number of accidents and the number of pedestrian accidents at the intersection for each year of analysis. |
| 7 | Pedestrian Volume Distribution | Provides an hourly distribution of pedestrian volumes at the intersection. |
| 8 | Pedestrian Accident Details | Information includes detailed pedestrian accident data such as date, time, weather conditions, pedestrian age, pedestrian/vehicle actions and violations, contributing circumstances, and other factors related to each accident. |

Once these errors were corrected, a second computer program was developed to further check the data. This program produced a display of the intersection data for each approach leg to provide a complete picture of the intersection. The intersection diagrams were manually compared to the raw data to check for proper intersection orientation, operations, speeds, approach widths, traffic and pedestrian volumes, turning movements, number of lanes, turn restrictions, RTOR restrictions, parking, and bus codes. This check was made to insure accurate data processing. Discrepancies were readily noted and subsequently corrected in the computer files.

A data reformating program was developed to condense the intersection data file to facilitate analysis using the Statistical Package for the Social Sciences (SPSS) package. The program was designed to take the information collected for each intersection and categorize it for use in this analysis. For example, volume data for each intersection leg was added to derive the total intersection volume. The revised data file consisted of three cards per location. The first card contained dependent variables such as average annual pedestrian accidents, and pedestrian accidents by accident type, age group, severity, and lighting conditions. Card two of the reduced data file consisted of variables such as total and peak hour vehicle volumes, turning movements, pedestrian volumes, main-cross street volume ratio. The third card contained classification variables for the intersection such as operation code, land use code, approach speed code, pedestrian signal operations code, lane geometry code, and others. The data layout and abstract for the full and reduced data files are provided in Appendixes B and C, respectively.

## Data Analysis

A comprehensive statistical analysis was undertaken on the reduced data file to determine the effects of pedestrian signals on accidents. It was recognized that small samples of pedestrian accidents per site would exist, which would produce a skewed (non-normal) distribution of accidents by site. This required the selection of not only a large number of sites and 3 to 6 years of accident data, but also the selection of appropriate statistical tests. Basic statistics were first used to review the pedestrian accident characteristics. Next, correlation analysis was used to determine the traffic and roadway variables most highly related to pedestrian accidents. A branching analysis was used to indicate variables which explained the most variation in pedestrian accidents and to identify the important breakpoint levels for use in subsequent statistical tests.

Based on the results of the correlation and branching analyses, chi-square and analysis of variance and covariance tests were applied. The chi-square test was used to compare the distribution of accidents for locations with and without pedestrian signals and for different timing schemes (i.e., concurrent vs. exclusive timing) for various data groups. Finally, analysis of variance and covariance tests were used to isolate the effect of pedestrian signals and timing strategies on accidents, while controlling for other influencing variables. A discussion of the results of each type of analysis is given below, following descriptions of the data base.

Pedestrian Accident Characteristics

The accident data collected and analyzed in this study consisted of 2,081 pedestrian-vehicle accidents collected at the 1,297 intersections. Pedestrian accidents were defined as those which occurred within 80 feet (24 m) of the intersection on any approach. The analysis period for each city varied from 3 to 6 years based on the availability of accident data. In most cities, individual accident reports were obtained and reviewed. However, where the computerized accident reports provided information in sufficient detail, they were utilized to determine the characteristics of the accidents.

Each accident report was carefully screened to determine if the accident was intersection-related and related to a street crossing activity within the influence of the signal at the intersection. Several types of pedestrian accidents were eliminated from the data base, including:

- Pedestrian not in roadway
- Police officer directing traffic
- Too far from intersection such as more than 80 feet (24 m) from curb face
- Boarding/disembarking a vehicle (car or bus)
- Pedestrian working on a vehicle in street when struck
- "Pedestrians" riding bicycles across the street (pedestrians walking their bicycles were included)
- Others not related to the intersection

Subsequently, the 2,081 pedestrian accidents utilized in this study included only intersection accidents involving street crossing pedestrian movements.

Table 4 shows a breakdown of the pedestrian accidents by day of the week. The largest percentage of accidents occurred on Friday (18.5 percent), while the lowest percentage of accidents occurred on Sunday (6.9 percent). A summary showing time of day occurrences is provided in Table 5. The data indicates that the period between 3:00 to 4:00 p.m. accounted for 10.1 percent of the accidents, while 27.7 percent of the pedestrian accidents occurred during the p.m. peak period (3:00 to 6:00 p.m.).

Table 4. Pedestrian accident summary by day of week.

| Day of Week | Number | Percent |
|---|---|---|
| Sunday | 143 | 6.9 |
| Monday | 309 | 14.8 |
| Tuesday | 345 | 16.6 |
| Wednesday | 307 | 14.7 |
| Thursday | 313 | 15.0 |
| Friday | 384 | 18.5 |
| Saturday | 255 | 12.3 |
| Day Unknown | 25 | 1.2 |
| Total | 2,081 | 100.0 |

Table 5. Pedestrian accident summary by time of day.

| Time of Day | Number | Percent |
|---|---|---|
| Midnight to 1:00 a.m. | 33 | 1.6 |
| 1:00 a.m. to 2:00 a.m. | 19 | 0.9 |
| 2:00 a.m. to 3:00 a.m. | 29 | 1.4 |
| 3:00 a.m. to 4:00 a.m. | 7 | 0.3 |
| 4:00 a.m. to 5:00 a.m. | 4 | 0.2 |
| 5:00 a.m. to 6:00 a.m. | 10 | 0.5 |
| 6:00 a.m. to 7:00 a.m. | 48 | 2.3 |
| 7:00 a.m. to 8:00 a.m. | 90 | 4.3 |
| 8:00 a.m. to 9:00 a.m. | 120 | 5.8 |
| 9:00 a.m. to 10:00 a.m. | 72 | 3.5 |
| 10:00 a.m. to 11:00 a.m. | 89 | 4.3 |
| 11:00 a.m. to Noon | 93 | 4.5 |
| Noon to 1:00 p.m. | 132 | 6.3 |
| 1:00 p.m. to 2:00 p.m. | 123 | 5.9 |
| 2:00 p.m. to 3:00 p.m. | 160 | 7.7 |
| 3:00 p.m. to 4:00 p.m. | 210 | 10.1 |
| 4:00 p.m. to 5:00 p.m. | 180 | 8.6 |
| 5:00 p.m. to 6:00 p.m. | 187 | 9.0 |
| 6:00 p.m. to 7:00 p.m. | 117 | 5.6 |
| 7:00 p.m. to 8:00 p.m. | 111 | 5.3 |
| 8:00 p.m. to 9:00 p.m. | 70 | 3.4 |
| 9:00 p.m. to 10:00 p.m. | 51 | 2.5 |
| 10:00 p.m. to 11:00 p.m. | 64 | 3.1 |
| 11:00 p.m. to Midnight | 52 | 2.5 |
| Not Known | 10 | 0.4 |
| Total | 2,081 | 100.0 |

Tables 6 through 8 provide summaries of pedestrian accidents by weather, road surface conditions, and lighting conditions respectively. These tables indicate that most pedestrian accidents occur during favorable weather and road surface conditions, and during daylight hours. However, these results are not surprising, since most pedestrian activity occurs during daylight hours and under favorable weather conditions. Note that the pedestrian accidents in Washington, D.C. were not included in Tables 6 and 8 because information on weather and lighting conditions was not available.

Table 6. Pedestrian accidents by weather condition*.

| Weather Condition | Number | Percent |
|---|---|---|
| Clear/Cloudy | 1,317 | 79.5 |
| Fog | 22 | 1.3 |
| Rain | 247 | 14.9 |
| Snow | 56 | 3.4 |
| Unknown | 14 | 0.9 |
| Total* | 1,656 | 100.0 |

*Excludes accident data from Washington, D.C. where this information was not readily available.

Table 7. Pedestrian accidents by road surface conditions.

| Road Surface Condition | Number | Percent |
|---|---|---|
| Dry | 1,451 | 69.7 |
| Wet | 515 | 24.8 |
| Snowy/Icy | 86 | 4.1 |
| Unknown | 29 | 1.4 |
| Total | 2,081 | 100.0 |

Table 8. Pedestrian accidents by lighting condition.

| Lighting Condition | Number | Percent |
|---|---|---|
| Day | 1,137 | 68.6 |
| Dawn/Dusk | 88 | 5.3 |
| Dark with Street Lights | 395 | 23.9 |
| Dark without Street Lights | 25 | 1.5 |
| Unknown | 11 | 0.7 |
| Total* | 1,656 | 100.0 |

*Excludes accident data from Washington, D.C. where this information was not readily available.

A summary of accident severity is shown in Table 9. Of the 2,081 pedestrian accidents, 29 (1.4 percent) resulted in fatalities to the pedestrian. The 34 accidents of unknown severity are due either to the pedestrian leaving the scene of the accident, or the failure of the officer to provide severity information. It should be mentioned that many non-injury pedestrian accidents in urban areas are not reported, and therefore never become a part of the accident data base. This is often the case when the pedestrian has not sustained an injury, and there is no damage to a vehicle, leading the parties involved to decide that there is no reason to report the accident. In a few cases, however, a pedestrian or motorist involved in a pedestrian accident will report the accident to the police, even though the pedestrian claimed to be unhurt. However, there is no reliable way to account for unreported pedestrian accidents at a site.

Table 9. Pedestrian accidents by severity classification.

| Severity | Number | Percent |
|---|---|---|
| Fatal | 29 | 1.4 |
| Injury | 1,935 | 93.0 |
| No Injury | 98 | 4.7 |
| Unknown Severity | 19 | 0.9 |
| Total | 2,081 | 100.0 |

Data on age of the pedestrian was obtained for 1,021 accidents and was summarized into five age classifications as shown in Table 10. Of the 1,021 pedestrian accidents, 186 of them (18.2 percent) involved pedestrians who were 60 years of age or older. In addition, it was found that a higher percentage of accidents involved male pedestrians (55 percent) than female pedestrians (45 percent). Data were not available for Chicago, Illinois, or Washington, D.C. for use in Table 10.

Table 10. Pedestrian accidents by age group*.

| Age Group | Number | Percent |
|---|---|---|
| 0 - 15 | 225 | 22.0 |
| 16 - 30 | 255 | 25.0 |
| 31 - 45 | 119 | 11.7 |
| 46 - 59 | 130 | 12.7 |
| 60+ | 186 | 18.2 |
| Age Unknown | 106 | 10.4 |
| Total | 1,021 | 100.0 |

*Excludes accident data from Chicago, Illinois and Washington, D.C. where this data was not readily available.

The pedestrian action in 966 of the accidents (where the information was available) is summarized in Table 11 (excludes data from Washington, D.C., Chicago, Illinois, and Richmond, Virginia). Of the five categories shown in this table, only the first category (walking with the signal) is considered to represent a safe pedestrian crossing maneuver and 475 pedestrians (49.2 percent) involved in an accident were crossing properly. Pedestrians ran into the roadway (either with or against the signal) in 208 (21.5 percent) of the pedestrian accidents and violated the signal while walking in 229 cases (23.7 percent).

Table 11. Accidents by pedestrian violation.

| Pedestrian | Number | Percent |
|---|---|---|
| Walking With Signal | 475 | 49.2 |
| Walking Against Signal | 229 | 23.7 |
| Running With Signal | 24 | 2.5 |
| Running Against Signal | 184 | 19.0 |
| Other Hazardous Ped. Action | 12 | 1.3 |
| Unknown Ped. Action | 42 | 4.3 |
| Total | 966 | 100.0 |

A summary of driver maneuvers is shown in Table 12 for the total accident data base. About 60.3 percent of the pedestrian accidents involved drivers intending to go straight through the intersection. Right-turning vehicles were involved in 14.8 percent of the accidents and left-turning vehicles were involved in 22.5 percent of the accidents, which indicates a pedestrian safety problem with left-turning vehicles at signalized intersections. Of the 1,446 accidents where the driver action was known (Table 13), a total of 92 accidents (6.4 percent) involved a motorist violating the signal and 318 (22.0 percent) cases involved the driver failing to yield right-of-way during a turn. A hit-and-run event was noted in 140 accidents (9.7 percent).

Table 12. Pedestrian accidents by vehicle maneuver.

| Vehicle Maneuver | Number | Percent |
|---|---|---|
| Straight | 1,256 | 60.3 |
| Right-Turn | 308 | 14.8 |
| Left-Turn | 468 | 22.5 |
| Other/Unknown | 49 | 2.4 |
| Total | 2,081 | 100.0 |

Table 13. Pedestrian accidents by primary driver hazardous action.

| Driver Action | Number | Percent |
|---|---|---|
| Speeding | 18 | 1.2 |
| Failure to Yield ROW on Turn | 318 | 22.0 |
| Signal Violation | 92 | 6.4 |
| Driver Inattention | 90 | 6.2 |
| Hit and Run | 140 | 9.7 |
| Other Violation | 147 | 10.2 |
| No Driver Violation | 600 | 41.5 |
| Unknown Driver Action | 47 | 2.8 |
| Total | 1,446 | 100.0 |

*Excludes accident data from Chicago, Illinois where this information was not readily available.

## Intersection Characteristics

Data for this study were obtained for various intersections in fifteen U.S. cities as summarized in Table 2. The cities ranged in size from Chicago, Illinois to small suburban communities such as West Hartford, Connecticut. A total of 1,297 intersections were included in the study with a varying number of sites per city. The bulk of the locations were concentrated in the northeast and midwest sections of the country.

In keeping with the objectives of the study, intersections were selected on the basis of the type of pedestrian signalization in place. Table 2 provides a summary of the four categories of pedestrian signal timing used in the analysis. The number of intersections in each category varied by city as a function of local traffic engineering policies and standards. The bottom line of Table 2 indicates the relative percentages in each category.

A considerable amount of data were collected for each of the 1,297 intersections to provide a clear picture of the geometric features, auto and pedestrian flows, traffic control strategy, accident experience, and area conditions. Efforts were made to maintain a homogenous data base by considering only four-legged, signalized intersections. The intersections varied in a number of ways including:

- Traffic (auto and pedestrian) volumes
- Surrounding area type
- Number and type of approach lanes
- Signal timing parameters
- Road classification
- Operational features (i.e., one-way, two-way)

The following section describes the features of the intersections included in the data base.

For some types of data analysis, it was necessary to group locations in categories of traffic and pedestrian volume. This required that appropriate data groupings be developed. Various other roadway variables were used as control variables (or covariates) in the analysis of covariance. The following is a discussion of some of the key roadway variables and the distribution of the data base by those variables, including:

- Traffic and pedestrian volume
- Signal control type
- Bus traffic
- Intersection operations and design
- Speed limit
- Timing of signal
- Area type

Vehicle and Pedestrian Volumes: A wide range of vehicular and pedestrian volumes are represented in the data base. Volume categories were established by computing the mean vehicular and pedestrian volumes and the respective standard deviations for the 1,297 intersections in the sample. These statistics are given in Table 14. Intersections were then placed in low, medium, and high categories of vehicular and pedestrian volumes as indicated in Table 15.

Table 14. Daily vehicular and pedestrian volume data summary.

| Item | Mean | Standard Deviation |
|---|---|---|
| Total Approach Volume | 24,528 | 12,034 |
| Right-Turn Volume | 2,623 | 1,712 |
| Left-Turn Volume | 2,472 | 1,779 |
| Total Turn Volume | 5,096 | 3,225 |
| Total Pedestrian Volume | 3,636 | 6,095 |

Table 15. Number (and percent) of intersections by vehicular and pedestrian volume categories.

| Daily Vehicular Volume Levels | Daily Pedestrian Volume Levels | | | |
|---|---|---|---|---|
| | Low 0-1,999 | Medium 1,200-3,499 | High 3,500 or more | Total (Percent) |
| Low 0-17,999 | 259 (20.0%) | 81 (6.2%) | 64 (4.9%) | 404 (31.1%) |
| Medium 18,000-27,499 | 174 (13.4%) | 120 (9.3%) | 152 (11.7%) | 446 (34.4%) |
| High 27,500 or more | 180 (13.9%) | 127 (9.8%) | 140 (10.8%) | 447 (34.5%) |
| Total (Percent) | 613 (47.3%) | 328 (25.3%) | 356 (27.4%) | 1,297 (100%) |

A volume classification scheme was established for use in subsequent analysis by forming all combinations of low, medium and high volume levels of pedestrians and vehicles. The resulting nine categories and the corresponding breakdowns by type of pedestrian control are given in Table 16.

Table 16. Breakdown of intersection traffic levels and type of pedestrian control.

| | Traffic Level Classification | Type of Pedestrian Control | | | | Total (Percent) |
|---|---|---|---|---|---|---|
| | | No Pedestrian Signal | Concurrent Pedestrian Signal Timing | Exclusive Pedestrian Phase | Other Pedestrian Signal Timing | |
| 1 | Low Pedestrians Low Vehicles | 127 (9.8%) | 120 (9.3%) | 12 (0.9%) | 0 (0.0%) | 259 (20.0%) |
| 2 | Medium Pedestrians Low Vehicles | 46 (3.5%) | 27 (2.1%) | 8 (0.6%) | 0 (0.0%) | 81 (6.2%) |
| 3 | High Pedestrians Low Vehicles | 16 (1.2%) | 22 (1.2%) | 21 (1.6%) | 5 (0.4%) | 64 (4.9%) |
| 4 | Low Pedestrians Medium Vehicles | 84 (6.5%) | 78 (6.0%) | 10 (0.8%) | 2 (0.2%) | 174 (13.4%) |
| 5 | Medium Pedestrians Medium Vehicles | 51 (3.9%) | 61 (4.7%0 | 8 (0.6%) | 0 (0.0%) | 120 (9.3%) |
| 6 | High Pedestrians Medium Vehicles | 37 (2.9%) | 89 (6.9%) | 25 (1.9%) | 1 (0.1%) | 152 (11.7%) |
| 7 | Low Pedestrians High Vehicles | 74 (5.7%) | 92 (7.1%) | 12 (0.9%) | 2 (0.2%) | 180 (13.9%) |
| 8 | Medium Pedestrians High Vehicles | 47 (3.6%) | 79 (6.1%) | 0 (0.0%) | 1 (0.1%) | 127 (9.8%) |
| 9 | High Pedestrians High Vehicles | 26 (2.0%) | 90 (6.9%) | 13 (1.0%) | 11 (0.8%) | 140 (10.8%) |
| | Total (Percent) | 508 (39.2%) | 658 (50.7%) | 109 (8.4%) | 22 (1.7%) | 1,297 (100.0%) |

Bus Traffic: The presence of bus traffic and bus stops at intersections is believed to influence pedestrian safety due to the visual obstructions posed by the bus and bus facilities (i.e., shelters) to both drivers and pedestrians. The existence of a bus route on either street was considered as a surrogate measure of the bus traffic influence. Three classifications were established to reflect the different situations for intersections in the sample. These were:

- Bus operations on both streets
- Bus operations on one street
- No bus operations through intersection

Table 17 shows the distribution of locations according to their respective bus operation features. It is obvious from the information in Table 17 that bus operations were common to most of the intersections used in the study. No attempt was made to address the influence of different bus frequencies or the impact of near or far side bus stops.

Table 17. Classification of intersections on the basis of bus operation code and pedestrian signalization.

| Type of Pedestrian Signalization | Bus Routes On Both Streets | Bus Routes On One Street | No Bus Routes |
|---|---|---|---|
| No Pedestrian Signal | 226 (17.4%) | 234 (18.0%) | 48 (3.7%) |
| Concurrent Pedestrian Signal Timing | 316 (24.4%) | 296 (22.8%) | 46 (3.6%) |
| Exclusive Pedestrian Signal Timing | 62 (4.8%) | 40 (3.2%) | 7 (0.5%) |
| Other Pedestrian Signal Timing | 18 (1.4%) | 3 (0.2%) | 1 (0.1%) |
| Totals | 622 (47.9%) | 573 (44.2%) | 102 (7.9%) |

Intersection Operations and Design: The directions from which traffic approaches an intersection influences the number of pedestrian-motor vehicle conflict points and hence the difficulty of the pedestrian task. Three basic categories of intersection operation were defined:

- One-way street intersecting a one-way street
- One-way street intersecting a two-way street
- Two-way street intersecting a two-way street

Table 18 provides a summary of the number of intersections in each operational class by type of pedestrian control. It can be noted that most of the intersections (888) were classified as two-way operation.

Intersection skewness was another feature which was considered, since it was hypothesized that differences in sight lines and hence the visibility of pedestrians may influence the pedestrian accident experience. The sample included 243 skewed intersections, defined as any intersection for which one or more approaches did not intersect at a right angle. The angle of an intersection did not exceed 130 degrees in any case. The majority (1,054) of the intersections were orthogonal (at right angles) or very nearly so.

Table 18. Breakdown of intersection operation by type of pedestrian signal.

| Type of Pedestrian Signalization | Intersection Operations | | |
|---|---|---|---|
| | One-Way One-Way | One-Way Two-Way | Two-Way Two-Way |
| No Pedestrian Signal | 49 (3.8%) | 94 (7.2%) | 365 (28.2%) |
| Concurrent Pedestrian Signal Timing | 76 (5.8%) | 118 (9.0%) | 464 (35.8%) |
| Exclusive Pedestrian Signal Timing | 44 (3.4%) | 17 (1.3%) | 48 (3.7%) |
| Other Pedestrian Signal Timing | 4 (0.3%) | 7 (0.5%) | 11 (0.8%) |
| Totals | 173 (13.3%) | 236 (18.2%) | 888 (68.5%) |

Speed Limit: Intersections were also classified by speed limit to assess the possible influence of traffic speeds on pedestrian safety. The posted speed limit was assumed to have some relationship to vehicle approach speeds, since speed data were not available on each approach. Locations were classified into two groups; locations with speed limits of 35 mph (56 kph) or lower and all others. The majority of intersections (93.4 percent) were classified into the first group, which generally reflects the speed limits for most urban arterial and collector streets. Group two included 85 locations at which one or more legs had approach speeds higher than 35 mph (56 kph).

Signalization Features: Data were also obtained for the type and operation of traffic signals at the study sites. The majority of locations (87.4 percent) were under fixed-time signal control. The others were under various forms of actuated control. Table 19 provides a summary of the distribution of signal control by type of pedestrian signalization.

Signal cycle length data were also collected to allow analysis of the influence of pedestrian wait time, a function of the signal cycle length, on safety. Three categories were established to differentiate the sample intersections. These categories were intersections with cycle lengths

Table 19. Type of signal control by type of pedestrian signalization.

| | Type of Signal Controller | |
|---|---|---|
| Type of Pedestrian Signalization | Fixed Time | Actuated |
| No Pedestrian Signal | 458 (35.3%) | 50 (3.9%) |
| Concurrent Pedestrian Signal Timing | 581 (44.8%) | 77 (5.9%) |
| Exclusive Pedestrian Signal Timing | 72 (5.6%) | 37 (2.9%) |
| Other Pedestrian Signal Timing | 22 (1.7%) | 0 (0.0%) |
| Totals | 1133 (87.4%) | 164 (12.6%) |

less than or equal to 60 seconds, intersections with cycles greater than 60 seconds, and actuated control intersections. Table 20 provides the cross tabulation of signal cycle length by type of pedestrian signalization. The data indicated that most intersections (76.5 percent) were fixed time with a signal cycle length greater than 60 seconds.

Table 20. Signal cycle length by type of pedestrian signalization.

| | Signal Cycle Length | | |
|---|---|---|---|
| Type of Pedestrian Signalization | Less Than or Equal to 60 Seconds | Greater Than 60 Seconds | Actuated |
| No Pedestrian Signals | 71 (5.5%) | 387 (29.8%) | 50 (3.9%) |
| Concurrent Pedestrian Signal Timing | 69 (5.3%) | 512 (39.5%) | 77 (5.9%) |
| Exclusive Pedestrian Signal Timing | 1 (0.1%) | 71 (5.5%) | 37 (2.9%) |
| Other Pedestrian Signal Timing | 0 (0.0%) | 22 (1.7%) | 0 (0.0%) |
| Totals | 141 (10.9%) | 992 (76.5%) | 164 (12.6%) |

Area Type: The type of area in which the intersection was located was included in the analysis as a possible influence on pedestrian accident experience. The urban area types defined in the Highway Capacity Manual were selected for use in this study [9]. Table 21 shows the distribution of intersections into classifications of CBD (central business district), CBD fringe, OBD (outlying business district), and residential area types. Most of the intersections selected for use in this study were found in residential areas. Exclusive pedestrian signal timing was found most often in CBD areas where heavy pedestrian volumes occur.

Table 21. Classification of intersections by area type code and type of pedestrian signalization.

| Type of Pedestrian Signalization | Area Type | | | |
|---|---|---|---|---|
| | CBD | CBD Fringe | Outlying Business District | Residential |
| No Pedestrian Signal | 85 (6.6%) | 72 (5.6%) | 51 (4.0%) | 299 (23.3%) |
| Concurrent Pedestrian Signal Timing | 135 (10.5%) | 69 (5.3%) | 62 (4.8%) | 386 (29.9%) |
| Exclusive Pedestrian Signal Timing | 70 (5.4%) | 7 (0.5%) | 3 (0.2%) | 29 (2.2%) |
| Other Pedestrian Signal Timing | 10 (0.8%) | 4 (0.3%) | 0 (0.0%) | 7 (0.5%) |
| Totals | 300 (23.3%) | 152 (11.8%) | 116 (9.0%) | 721 (55.9%) |

## Results

Based on the data collection and stratification discussed previously, a formal analysis approach was undertaken to address numerous questions regarding pedestrian signals and safety. In particular, some of the key analysis questions addressed were as follows:

1. What traffic and roadway factors explain the greatest amount of variance in pedestrian accidents?

2. Are pedestrian accidents significantly affected by the presence or absence of pedestrian signals?

3. Does the pedestrian signal timing scheme (i.e., standard timing, scramble timing, etc.) have a significant impact on pedestrian accidents?

4. Are pedestrian accidents affected by pedestrian signals and timing similarly in various cities?

5. How are various pedestrian accident types (i.e., right-turn pedestrian accidents, through pedestrian accidents, etc.) and severity of pedestrian accidents affected by pedestrian signals and timing schemes.

The analysis plan was structured to answer these and other related questions. The specific statistical tests selected for answering these questions include:

- Correlation analysis
- Branching analysis
- Chi-square analysis
- Analysis of variance and covariance

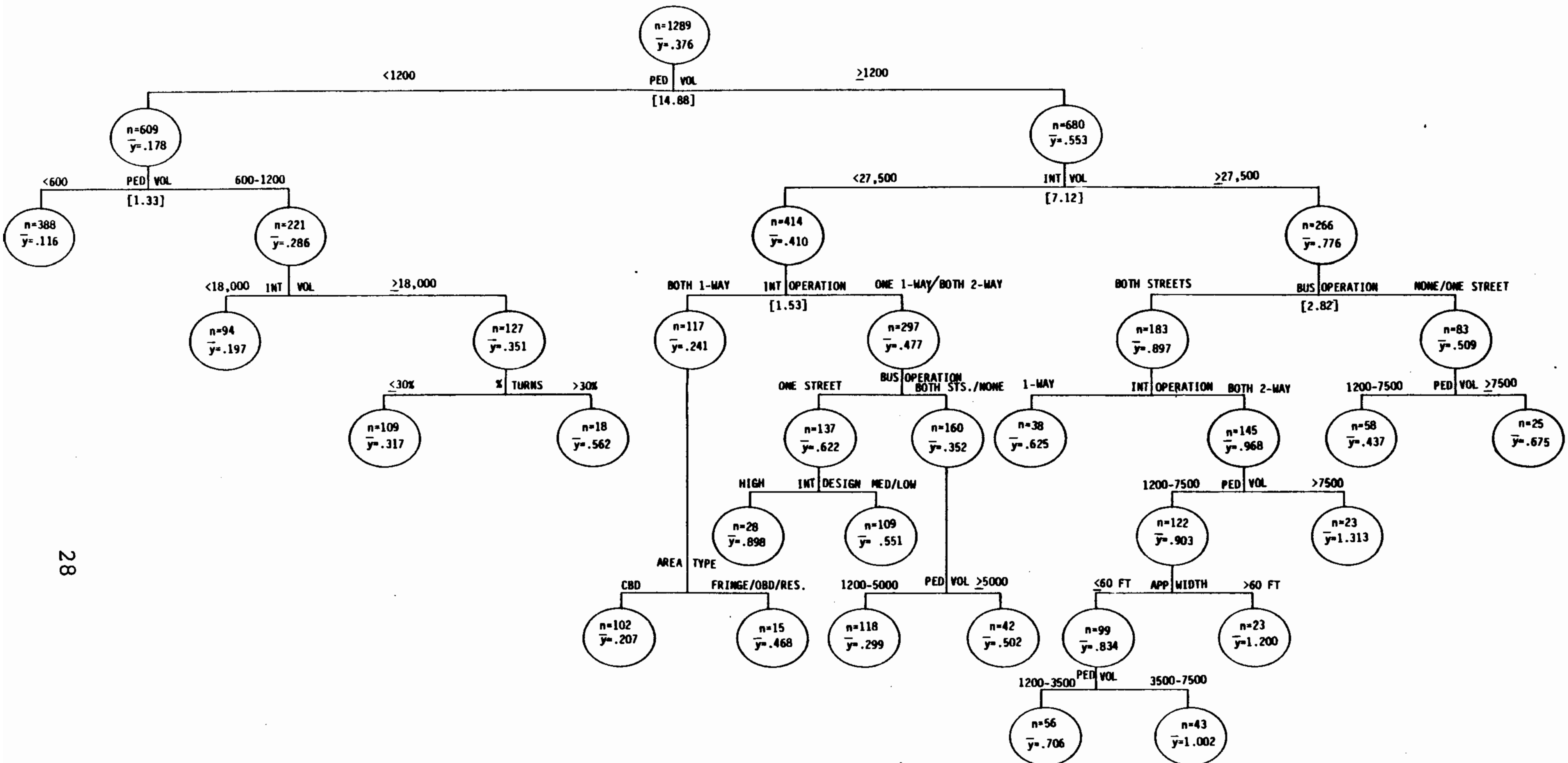
The results of these tests are discussed below.

## Correlation Analysis

The purpose of this analysis was to determine which independent variables (i.e., traffic, roadway, and signal variables) to include in subsequent analyses based on their relationships to each other and accident data (dependent variables). Pearson's correlations were computed for various combinations of continuous dependent and independent variables to determine those combinations having the strongest interrelationships. The correlations between key dependent variables and independent variables were generally low (r-values of less than 0.6). The strongest relationships were found between mean pedestrian accidents per year and both pedestrian volumes and vehicle volumes. Generally low correlations were expected due to the wide variety of factors influencing the pedestrian accident experience at a location. No attempt was made to improve the correlations through the inclusion of multiple independent variables, by step-wise linear regression analysis or through data stratification. The decision was made to proceed to other analysis techniques (branching analysis and analysis of covariance) to further quantify the effect of individual variables on pedestrian accidents.

## Branching Analysis

A branching analysis was conducted to determine what traffic and roadway variables explain the variation in pedestrian accident experience. Also, it was hoped that the analysis would identify breakpoint levels of pedestrian and traffic volumes, based upon accident experience, for data stratification in subsequent analyses. The results of the branching analysis are shown in Figure 1, which indicated the following:




**Legend:**

n = number of cases in each group
ȳ = mean pedestrian accidents per year for each group
[ ] = variation explained at each branch
(Variation Explained = 36.6%)

Note: 1 foot = 0.3 m.

Figure 1. Branching analysis using mean pedestrian accidents per year.

- Pedestrian volume is the variable which explains the greatest amount of variation in pedestrian accidents (14.9 percent of variance explained).

- After testing several groupings of pedestrian volume, the most important breakpoint in pedestrian accidents occurs for a level of 1,200 pedestrians per day. In fact, for the 609 locations with daily pedestrian volumes less than 1,200, the mean pedestrian accidents (per location per year) was 0.178, compared to 0.553 for locations with daily pedestrian volumes of 1,200 or more. Another breakpoint occurred at a daily pedestrian volume of 3,500.

- The most important breakpoints in the traffic volume data (in terms of pedestrian accidents) occurred at daily volume levels of 27,500 and 18,000.

- Besides pedestrian and traffic volume, other variables which were found to be of some importance in explaining pedestrian accidents included:

  - Bus operation (i.e., a bus route on one or more of the streets at the intersection)

  - Street operation (i.e., one-way or two-way operations)

  - Percent turning vehicles

  - Intersection design

  - Area type (i.e., CBD, OBD, fringe, or residential)

  - Street approach width

- While all intersections in the analysis had a traffic signal, the presence or absence of a pedestrian signal indication had no significant effect on pedestrian accident experience.

Further branching analysis was conducted separately for the following three groups of intersections: (1) the 507 intersections with no pedestrian signals; (2) the 652 locations with concurrent pedestrian signals; and (3) the 109 locations with exclusive pedestrian signal timing. The following general conclusions were reached:

- The presence of buses was found to be an important factor in pedestrian accidents for location groups above 1,000 pedestrians per day for locations with concurrent pedestrian timing and locations with no pedestrian signals.

- For exclusive timed signals with daily pedestrian volumes above 8,000, pedestrian accidents were much lower at the intersection of one-way streets than for intersections with two-way street approaches.

- For intersections with no pedestrian signals on bus routes and average daily pedestrian volumes above 1,000, a high accident experience was found at residential intersections compared to non-residential (i.e., CBD, OBD, and CBD fringe) areas.

- The presence of a wide street was associated with higher pedestrian accidents for some categories of roads with daily pedestrian volumes above 1,000.

Three classes of traffic volume were chosen based on breakpoints determined from the branching analysis to assess the sensitivity of pedestrian accidents as a function of pedestrian and traffic volume as illustrated in Figure 2. Various classes of pedestrian and traffic volume were grouped together and the three year totals of pedestrian accidents were plotted. Three traffic volume groups and 11 pedestrian volume groups were used to represent the expected number of pedestrian accidents at an intersection for a three year period. The plots include intersections with no pedestrian signals and also those with concurrent pedestrian signals (since no significant difference was found in pedestrian accidents between these two groups). The curves show the sensitivity of pedestrian accidents to traffic and pedestrian volumes. Calculation of correlation coefficients (Pearson's r) is not appropriate in this case, since each data point represents the mean accident experience of numerous intersections within a particular volume class.

Based on the results of the branching analysis, a breakdown analysis was used to summarize average pedestrian accidents for various classifications of traffic volume, pedestrian volume, and signal timing scheme (Table 22). This breakdown table provides a simplistic means to estimate pedestrian accidents in relation to pedestrian signalization and volume factors. These results are not, however, sufficient to make conclusive statements without further testing using more sophisticated analysis of variance tests or analyzing in greater detail the influence of other geometric, traffic, and locational factors.

## Chi-Square Analysis

The chi-square test was used to determine if a statistically significant association existed between pedestrian accidents and pedestrian signal timing schemes (including the no pedestrian signal situation). The chi-square test is appropriate for use in this study, since it can relate a continuous, non-normal variable (i.e., Poisson distribution of accidents) to one or more categorical variables (i.e., categories of pedestrian signal timing).

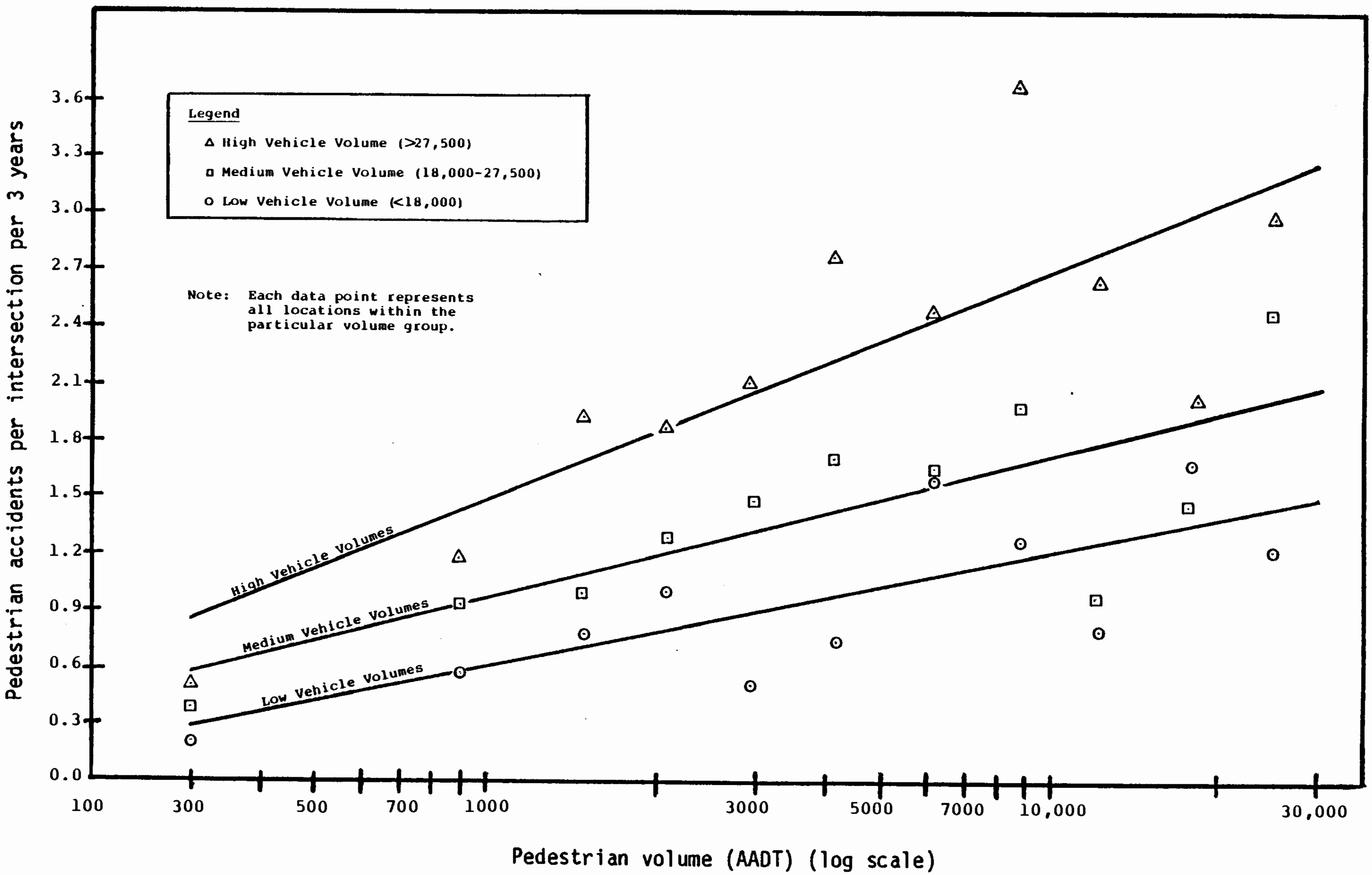



Figure 2. Relationship between pedestrian volume and pedestrian accident experience for three levels of vehicle volume.

Table 22. Summary of pedestrian accidents per year per site by pedestrian signal type and volume class.

| Volume Class | Pedestrian Signalization Alternative | | |
|---|---|---|---|
| | No Pedestrian Signal | Concurrent Timed Pedestrian signals | Exclusive Timed Pedestrian Signals |
| 1. Low Pedestrian Volume (0-1,200) Low Vehicle Volume (0-18,000) | 0.09 (127) | 0.14 (120) | 0.11 (12) |
| 2. Medium Pedestrian Volume (1,201-3,500) Low Vehicle Volume (0-18,000) | 0.28 (46) | 0.25 (27) | 0.40 (8) |
| 3. High Pedestrian Volume (greater than 3,500) Low Vehicle Volume (0-18,000) | 0.25 (16) | 0.50 (22) | 0.29 (21) |
| 4. Low Pedestrian Volume (0-1,200) Medium Vehicle Volume (18,001-27,500) | 0.19 (84) | 0.21 (78) | 0.08 (10) |
| 5. Medium Pedestrian Volume (1,201-3,500) Medium Vehicle Volume (18,001-27,500) | 0.41 (51) | 0.41 (61) | 0.20 (8) |
| 6. High Pedestrian Volume (greater than 3,500) Medium Vehicle Volume (18,001-27,500) | 0.65 (37) | 0.52 (89) | 0.21 (25) |
| 7. Low Pedestrian Volume (0-1,200) High Vehicle Volume (greater than 27,500) | 0.23 (74) | 0.28 (92) | 0.17 (12) |
| 8. Medium Pedestrian Volume (1,201-3,500) High Vehicle Volume (greater than 27,500) | 0.52 (47) | 0.73 (79) | - |
| 9. High Pedestrian Volume (greater than 3,500) High Vehicle Volume (greater than 27,000) | 0.88 (26) | 0.91 (90) | 0.66 (13) |

X.XX - Mean Pedestrian Accidents/Intersection/Year
(XXX) - Number of Intersection

The distributions of locations with various pedestrian signal schemes were separately established for pedestrian volumes less than 1,200 per day (Table 23) and for 1,200 or more pedestrians per day (Table 24). Four to five ranges of pedestrian accidents (per three-year period) were developed for use in the chi-square analysis. The number and percentages of locations in each category are given in Tables 23 and 24. These indicate a highly skewed (i.e., Poisson) distribution for each group of locations. The breakpoint of 1,200 pedestrians per day was used to separate the data set because of its importance in explaining variation in pedestrian accidents (as found from the branching analysis).

The results of the chi-square analysis are summarized in Table 25 and indicate the following:

- No significant difference was found in pedestrian accident distributions when comparing locations with no pedestrian signals to locations with concurrent pedestrian signals. This was true for both groups of pedestrian volume (i.e., less than 1,200 and greater than or equal to 1,200 pedestrians per day).

- For intersections with less than 1,200 pedestrians per day, no significant difference was found in pedestrian accident distributions when comparing exclusive-timed pedestrian signals with both the no pedestrian signal group and the concurrent pedestrian signal group.

- For intersections with 1,200 or more pedestrians per day, a significant difference was found between accident distributions for locations with exclusive-timed pedestrian signals compared to locations with no pedestrian signal and locations with concurrent pedestrian signals (0.01 level of significance in each case). A higher proportion of exclusive-time locations were in the low accident groups than with the concurrent signal group or the no pedestrian signal group.

## Analysis of Variance and Covariance

The statistical investigations were pursued to a still higher level in an attempt to explain the findings of the previous analyses. This involved the use of analysis of variance and covariance techniques. The analysis of variance (ANOVA) method was used to divide the observed variation in experimental data into parts, with each part assigned to a known source or variable. The purpose of the analysis was to determine whether a particular part of the variation is greater than would be expected by chance. The null hypothesis generally assumed for the analysis of variance was that the pedestrian accident experience is not significantly different between two or more groups of sites (i.e., comparing sites with no pedestrian signals to sites with standard-timed pedestrian signals).

Table 23. Distribution of locations by pedestrian accident experience and signal timing scheme for locations with pedestrian volumes less than 1,200 per day.

| Pedestrian Accidents Per 3 Years | Number of Intersections (Percent) | | |
|---|---|---|---|
| | No Pedestrian Signal | Cuncurrent Timed Pedestrian Signals | Exclusive Timed Pedestrian Signals |
| 0.00 | 177 (62.1) | 155 (53.4) | 25 (73.5) |
| 0.01 - 1.00 | 71 (24.9) | 81 (27.9) | 5 (14.7) |
| 1.01 - 1.50 | 14 (4.9) | 27 (5.9) | 2 (5.9) |
| Greater than 1.50 | 23 (8.1) | 37 (12.8) | 2 (5.9) |
| Totals | 285 (100.0) | 290 (100.0) | 34 (100.0) |

Table 24. Distribution of locations by pedestrian accident experience and signal timing scheme for locations with pedestrian volumes of 1,200 or more per day.

| Pedestrian Accidents Per 3 Years | Number of Intersections (Percent) | | |
|---|---|---|---|
| | No Pedestrian Signal | Cuncurrent Timed Pedestrian Signals | Exclusive Timed Pedestrian Signals |
| 0.00 | 57 (25.5) | 64 (17.4) | 32 (42.7) |
| 0.01 - 1.00 | 64 (28.7) | 99 (26.9) | 25 (33.3) |
| 1.01 - 1.50 | 29 (13.0) | 46 (12.5) | 3 (4.0) |
| 1.51 - 2.25 | 28 (12.6) | 58 (15.8) | 7 (9.3) |
| Greater than 2.25 | 45 (20.2) | 101 (27.4) | 8 (10.7) |
| Totals | 223 (100.0) | 368 (100.0) | 75 (100.0) |

Note: Pedestrian accident data were collected for 3 to 6 years at each site and accidents were normalized to a 3-year period. Thus, for many sites, whole numbers did not result. For example, 3 pedestrian accidents in a 4-year period corresponds to 0.75 accidents per year, or 2.25 accidents per 3 years.

Table 25. Summary of results from chi-square analysis.

| Comparison | Sample of Intersections Used - Pedestrian Volume Category | Significant Difference In Accident Distributions (0.05 Level) | Chi-Square Value | Degrees of Freedom | Level of Significance |
|---|---|---|---|---|---|
| No Pedestrian Signal vs. Concurrent-Timed Pedestrian Signal | Less than 1,200 per day | No | 5.630 | 3 | - |
| | Greater than 1,200 per day | No | 8.664 | 4 | - |
| No Pedestrian Signal vs. Exclusive-Timed Pedestrian Signal | Less than 1,200 per day | No | 2.197 | 3 | - |
| | Greater than 1,200 per day | Yes | 13.492 | 4 | 0.01 |
| Concurrent-Timed Pedestrian Signal vs. Exclusive-Timed Pedestrian Signal | Less than 1,200 per day | No | 5.410 | 3 | - |
| | Greater than 1,200 per day | Yes | 32.240 | 4 | 0.01 |

The analysis of covariance is similar to the analysis of variance (ANOVA), but it allows for the inclusion of covariates in the analysis to adjust the dependent variable (i.e., pedestrian accidents per year) for continuous variables where appropriate. For example, the continuous covariates selected and used in most of the ANOVA tests were pedestrian volume and traffic volume. This allowed for determining the effect of pedestrian signals on pedestrian accidents while controlling for the effects of varying levels of pedestrian and traffic volumes. Examples of the discrete (non-continuous) variables included as covariates in the analysis included street operation, absence or presence of right-turn-on-red regulations, bus operation, area type, lane geometry, and others.

The final selection of variables used in the ANOVA analysis was based on the results of the correlation analysis, the branching analysis, and preliminary ANOVA runs. The dependent variables used in the ANOVA runs included various stratifications of mean annual pedestrian accidents, including:

- Total accidents
- Right-turn accidents
- Left-turn accidents
- Total turn accidents
- Through pedestrian accidents
- Severe injury accidents
- Young pedestrian accidents
- Elderly pedestrian accidents

The independent variables which were used in one or more of the ANOVA runs as covariates included:

- Total traffic volume (AADT)
- Right-turn traffic volume (AADT)
- Left-turn traffic volume (AADT)
- Total turning traffic volume (AADT)
- Total pedestrian volume (AADT)

The ANOVA runs were made with varying combinations of the following classification variables:

- Area type code (i.e., CBD, CBD Fringe, OBD, Residential)
- Street operation (i.e., one-way and two-way streets)
- Signal operation code (i.e., no pedestrian signal, concurrent pedestrian signals, exclusive timing)
- City code (i.e., Chicago, Detroit, Denver, etc.)
- Right-turn-on-red prohibitions

Finding 2-2: Similar comparisons were also made with mean turning pedestrian accidents per year. The independent variables included operation code, pedestrian volume, and total vehicle turning volume. There was a significant difference (at the 0.05 level) between no pedestrian signal locations and locations with concurrent pedestrian signals for the mean pedestrian turning accidents per year. The analysis also indicated that locations with no pedestrian signals had significantly fewer pedestrian turning accidents than those with concurrent pedestrian signals. However, a small sample size exists for turning accidents, and the mean pedestrian accidents per site per year for the two groups were 0.12 and 0.15, respectively. Thus, further in-depth testing is needed to verify this apparent effect. Details of the results are given in Table 26. This finding may be the result of pedestrians failing to be sufficiently cautious of turning vehicles at locations with pedestrian signal heads.

Finding 2-3: Comparisons of mean annual pedestrian accidents were made between locations with no pedestrian signal and concurrent pedestrian signals for the cities of Chicago, Detroit, Washington, Toledo, and Seattle (individually and as a group) to determine whether similar results were found in each major city. Again, the independent variables were traffic volume, pedestrian volume, signal operation, and street operation. No significant differences in pedestrian accidents were found in any city between intersections with no pedestrian signals versus intersections with concurrent pedestrian signals. When a similar analysis was conducted for the five cities combined (also controlling for the volumes), no significant differences were found in either the total mean pedestrian accidents, or the mean turning pedestrian accidents. This also indicates that the difference in mean turning accidents (found in the Finding 2.2) was likely due to different cities being in each category, rather than the signal timing itself. These findings are summarized in Table 27.

Issue #3: Is there any significant difference in pedestrian accidents between intersections with no pedestrian signals and intersections with exclusive pedestrian signal timing?

Finding 3-1: The mean pedestrian accidents per year are significantly different between intersections with exclusive timing schemes compared to intersections with no pedestrian signals (at the 0.001 level) when controlling for street operation, pedestrian volume, and traffic volume. The mean adjusted pedestrian accidents at exclusive-timed locations (0.15 per year) is significantly lower than for locations without pedestrian signals (0.33 per year). The chi-square analysis confirmed this finding for locations with average daily pedestrian volumes above 1,200.

Finding 3-2: Similar comparisons were also made with mean turning accidents per year. The independent variables included operation code, pedestrian volume, and vehicle turning volume. In each case, the mean adjusted accidents per year were significantly lower at exclusive-timed locations than at locations without pedestrian signals (at the 0.001 level of significance). Similar differences were also found in two separate analyses when using right-turn pedestrian accidents and left-turn pedestrian accidents as the dependent variables.

Table 26. Summary of ANOVA results for different pedestrian signal alternatives.

| Comparison | Dependent Variable | Adjusted Means (Sample Sizes in Parenthesis) | Control Variables | Significant Difference (at the 0.05 level) | Level of Significance |
|---|---|---|---|---|---|
| 1. All Ped. Signal Alternatives | A. Mean Pedestrian Accidents per Year | No Ped. Signal: 0.36 (508)<br>Concurrent: 0.40 (658)<br>Exclusive: 0.22 (109)<br>Other: 0.38 (22) | Pedestrian Volume (AADT)<br>Total Traffic Volume (AADT)<br>Street Operation (One-Way/ Two-Way)<br>Ped. Signal Alternatives | Yes | 0.001 |
| | B. Mean Pedestrian Turning Accidents per Year | No Ped. Signal: 0.13 (508)<br>Concurrent: 0.17 (658)<br>Exclusive: 0.01 (109)<br>Other: 0.20 (22) | Pedestrian Volume (AADT)<br>Total Traffic Volume (AADT)<br>Street Operation (One-Way/ Two-Way)<br>Ped. Signal Alternatives | Yes | 0.001 |
| 2. No Ped. Signal Indication vs. Concurrent Ped. Signal Timing | A. Mean Pedestrian Accidents per Year | No Ped. Signal: 0.36 (508)<br>Concurrent: 0.40 (658) | Pedestrian Volume (AADT)<br>Total Traffic Volume (AADT)<br>Street Operation (One-Way) Two-Way)<br>Ped. Signal Alternatives | No | 0.130 |
| | B. Mean Pedestrian Turning Accidents per Year | No Ped. Signal: 0.12 (508)<br>Concurrent: 0.15 (658) | Pedestrian Volume (AADT)<br>Total Traffic Volume (AADT)<br>Street Operation (One-Way/ Two-Way)<br>Ped. Signal Alternatives | Yes | 0.048 |
| 3. No Ped. Signal Indication vs. Exclusive Ped. Signal Timing | A. Mean Pedestrian Accidents per Year | No Ped. Signal: 0.33 (508)<br>Exclusive: 0.15 (109) | Pedestrian Volume (AADT)<br>Total Traffic Volume (AADT)<br>Street Operation (One-Way/ Two-Way)<br>Ped. Signal Alternatives | Yes | 0.001 |
| | B. Mean Pedestrian Turning Accidents per Year | No Ped. Signal: 0.11 (508)<br>Exclusive: 0.00 (109) | Pedestrian Volume (AADT)<br>Total Traffic Volume (AADT)<br>Street Operation (One-Way/ Two-Way)<br>Ped. Signal Alternatives | Yes | 0.001 |
| 4. Concurrent Ped. Signal Timing vs. Exclusive Ped. Signal Timing | A. Mean Pedestrian Accidents per Year | Concurrent Timing: 0.43 (658)<br>Exclusive: 0.27 (109) | Pedestrian Volume (AADT)<br>Total Traffic Volume (AADT)<br>Street Operation (One-Way/ Two-Way)<br>Ped. Signal Alternatives | Yes | 0.001 |
| | B. Mean Pedestrian Turning Accidents Per Year | Concurrent Timing: 0.17 (658)<br>Exclusive: 0.03 (109) | Pedestrian Volume (AADT)<br>Total Traffic Volume (AADT)<br>Street Operation (One-Way/ Two-Way)<br>Ped. Signal Alternatives | Yes | 0.001 |

Table 27. - Summary of ANOVA results by city.

| City | Dependent Variable | Adjusted Means (Sample Sizes in Parenthesis) | Control Variables | Significant Difference (at the 0.05 level) | Level of Significance |
|---|---|---|---|---|---|
| 1. Chicago, IL | Mean Pedestrian Accidents per Year | No Ped. Signal: 0.60 (112)<br>Concurrent: 0.72 (112) | Pedestrian Volume (AADT)<br>Total Traffic Volume (AADT)<br>Street Operation (One-Way/ Two-Way)<br>Ped. Signal Alternatives | No | 0.137 |
| 2. Detroit, MI | Mean Pedestrian Accidents per Year | No Ped. Signal: 0.44 (62)<br>Concurrent: 0.44 (108) | Pedestrian Volume (AADT)<br>Total Traffic Volume (AADT)<br>Street Operation (One-Way/ Two-Way)<br>Ped. Signal Alternatives | No | 0.919 |
| 3. Seattle, WA | Mean Pedestrian Accidents per Year | No Ped. Signal: 0.45 (41)<br>Concurrent: 0.39 (99) | Pedestrian Volume (AADT)<br>Total Traffic Volume (AADT)<br>Street Operation (One-Way/ Two-Way)<br>Ped. Signal Alternatives | No | 0.443 |
| 4. Toledo, OH | Mean Pedestrian Accidents per Year | No Ped. Signal: 0.15 (66)<br>Concurrent: 0.25 (113) | Pedestrian Volume (AADT)<br>Total Traffic Volume (AADT)<br>Street Operation (One-Way/ Two-Way)<br>Ped. Signal Alternatives | No | 0.078 |
| 5. Washington, DC | Mean Pedestrian Accidents per Year | No Ped. Signal: 0.37 (68)<br>Concurrent: 0.40 (104) | Pedestrian Volume (AADT)<br>Total Traffic Volume (AADT)<br>Street Operation (One-Way/ Two-Way)<br>Ped. Signal Alternatives | No | 0.591 |
| 6. Chicago, IL<br>Detroit, MI<br>Seattle, WA<br>Toledo, OH<br>Washington, DC | Mean Pedestrian Accidents per Year | No Ped. Signal: 0.41 (349)<br>Concurrent: 0.44 (536) | Pedestrian Volume (AADT)<br>Total Traffic Volume (AADT)<br>Street Operation (One-Way/ Two-Way)<br>Ped. Signal Alternatives<br>City Code | No | 0.375 |
| 7. Chicago, IL<br>Detroit, MI<br>Seattle, WA<br>Toledo, OH<br>Washington, DC | Mean Pedestrian Turning Accidents Per Year | No Ped. Signal: 0.15 (349)<br>Concurrent: 0.17 (536) | Pedestrian Volume (AADT)<br>Total Traffic Volume (AADT)<br>Street Operation (One-Way/ Two-Way)<br>Ped. Signal Alternatives<br>City Code | No | 0.193 |

Issue #4: Is there a significant difference in pedestrian accidents between intersections with concurrent pedestrian signal timing and intersections with exclusive pedestrian signal timing?

Finding 4-1: The total mean pedestrian accidents are significantly different (at the 0.001 level) between intersections with standard pedestrian signal timing and intersections with exclusive pedestrian signal timing when accounting for the effects of street operation, pedestrian volume and traffic volume. The mean adjusted pedestrian accidents at exclusive locations (0.27 per year) is significantly lower than the mean pedestrian accidents for standard signal timing (0.43 per year).

Finding 4-2: Similar comparisons were also made with mean turning accidents per year, right-turn pedestrian accidents, and left-turn pedestrian accidents. The independent variables included street operation, pedestrian volume, and total vehicle turning volume. The exclusive-timed intersections had significantly lower accident experience than the standard timed signal locations in all cases tested (0.001 level of significance).

Issue #5: What is the effect of pedestrian signals and timing on pedestrian accident severity and on various pedestrian ages?

Finding 5-1: Of the 2,081 pedestrian accidents in 15 cities used in the analysis, pedestrian age information was known for only 915 (44 percent) of the accidents. Thus, an insufficient sample of pedestrian accident data was available by age group for analysis, after subdividing the data base by type of pedestrian signal and signal timing. Also, a proper analysis of pedestrian accidents by age should include considerations of the volume of pedestrians by age group for each site, which was not available.

An analysis of the effect of pedestrian signals and timing on the severity of pedestrian accidents was also considered. Of the 2,081 pedestrian accidents, severity information was known for 2,062 (99.1 percent) of the accidents. However, 93 percent (1,935 accidents) involved pedestrian injury, and most of the cities did not adequately classify the injury levels (i.e., A-type, B-type, or C-type injury). Thus, since no detailed information was available on level of injury, formal analysis was not possible on the effects of pedestrian signals and signal timing on accident severity.

Issue #6: What traffic, geometric, and operational variables have a significant effect on pedestrian accidents at signalized urban intersections?

Finding 6-1: Based on numerous ANOVA runs, variables with a significant effect (0.05 level) on total pedestrian accidents for some intersection groups included:

- Urban area type - suburban streets had significantly higher pedestrian accidents than other (CBD, OBD, and fringe) areas.

- Street operation - intersections of one or more one-way street approaches had significantly fewer pedestrian accidents than intersections of two, two-way streets.

- The presence of bus routes on one or both streets of the intersection was associated with higher pedestrian accidents for some intersection subgroups.

## Summary and Conclusions

This study involved an attempt to determine the effect of pedestrian signals and signal timing strategies on pedestrian safety. The research approach involved the collection, reduction, and analysis of accident, traffic, and design data for 1,297 urban intersections (with 2,081 pedestrian accidents over a three to six year period) in 15 cities. The signalization options included no pedestrian signals, standard (concurrent) timing, exclusive timing, and other timing schemes. Insufficient samples were available from the "other" category for statistical analysis. The following is a summary of major findings from the analysis:

1. Several operational variables were found to have a significant effect on pedestrian accidents at urban signalized intersections. The branching and regression analysis indicated that pedestrian volume is the single most important variable in explaining the variation in pedestrian accidents and a significant, direct relationship exists. The most important breakpoints occur at pedestrian volume levels of 1,200 and 3,500 pedestrians per day (branching analysis).

2. Traffic volume is the second most important variable in explaining pedestrian accidents, and it also has a significant, direct relationship to pedestrian accidents (branching analysis, regression, and analysis of covariance). The important breakpoints occur at traffic volume levels of 27,500 and 18,000 vehicles per day. Other variables found to have an important but smaller effect on pedestrian accidents include street operation (one-way versus two-way), area type (CBD, OBD, fringe, or residential), street approach width, bus operation, percent turning vehicles, and intersection design.

3. 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 (analysis of covariance). This finding was supported by the result of the chi-square test for intersections with pedestrian volumes above 1,200. However, the chi-square test did not detect a difference for intersections with pedestrian volumes less than 1,200 per day, possibly due to the limited sample of exclusively-timed signal locations within that volume category.

4. 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) for a sample of more than 1,100 locations representing these two groups. This findings was also true in an analysis of the five largest cities (Chicago, Washington, D.C., Detroit, Seattle, and Toledo) in the sampler considered both individually and collectively.

Concurrent timing is by far the most commonly used pedestrian signal timing strategy. However, the use of pedestrian indications with concurrent timing was not found to be effective in reducing pedestrian accidents. Several possible reasons for their lack of effectiveness in reducing pedestrian accidents include:

- Poor pedestrian respect for and compliance to pedestrian signal indications in most cities.

- The presence of a pedestrian signal indication may tend to create a "false sense of security" and may cause many pedestrians to have the mistaken impression that they are fully protected and have no reason to use caution. The absence of a pedestrian indication at a signalized location sometimes gives pedestrians the feeling that they are "on their own". This could cause many pedestrians to exercise more caution regarding turning vehicles.

- The use of the flashing WALK has been shown in the study by Robertson [1] to be ineffective in adequately warning pedestrians to watch for turning vehicles. In fact, one study found that only 2.5 percent of the pedestrians understood the intended meaning of the flashing and steady WALK indications. Also, many states have not incorporated the flashing WALK into their state policies, which has caused non-uniformity in the use of pedestrian signal messages in the U.S.

- Some studies have found that the flashing DONT WALK indication (clearance interval) is also not understood by many pedestrians, and many pedestrians believe that traffic will be released during the flashing DONT WALK interval.

- Pedestrian actuation devices are used too infrequently by pedestrians and therefore the use and respect for pedestrian signals may be minimal at these locations [1].

## Recommendations

The results of these analyses, while raising questions about the effectiveness of current pedestrian signalization practice, are not believed to justify the wide-spread elimination of pedestrian signals. It is recommended, however, that city and state agencies take a closer look before indiscriminately installing pedestrian signals at all traffic signalized locations. Pedestrian signals are expensive to install and maintain and they may not be justified at many locations.

In areas of poor signal compliance, widespread installation of new pedestrian signals is not recommended, unless pedestrian signal compliance improves. Based on the findings of this study, additional research may be desirable to further quantify the optimal use of pedestrian signals, including the following topics:

- Determine the effect of intersection type on pedestrian safety by considering differences in functional classifications, lane configuration, crosswalk length, special signal phasing, etc.

- Assess the effect of regional differences in pedestrian behavior, accident reporting, pedestrian enforcement policies, etc.

- Investigate further the influence of pedestrian activities related to accident experience by type of pedestrian signal timing.

- Assess the impacts of general pedestrian compliance and understanding of signal indications on accident experience.

- Investigate the effect of symbolic pedestrian signals versus word messages in terms of pedestrian accidents and/or conflicts.

The completion of such additional research will be helpful in developing improved policies and practices for pedestrian signals.

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# CHAPTER II - DEVELOPMENT OF IMPROVED PEDESTRIAN WARRANTS FOR TRAFFIC SIGNALS

The 1978 version of the Manual on Uniform Traffic Control Devices (MUTCD) specifies eight warrants for the installation of a traffic signal. Of the eight warrants, Warrant 3 (Minimum Pedestrian Volume) and Warrant 4 (School Crossing) are related to pedestrians. According to the MUTCD, pedestrian signal indications (i.e., WALK/DONT WALK signals) shall be provided when a traffic signal is installed under the Pedestrian Volume or School Crossing Warrant [1]. Warrants 6 (Accident Experience) and 8 (Combination of Warrants) also allow for some consideration of pedestrians. Additionally, the MUTCD requires pedestrian signal indications when: (1) an exclusive pedestrian phase is provided; (2) vehicular signal indications are not visible to pedestrians; and (3) at signalized school crossing intersections.

Also, the MUTCD suggests that pedestrian signal indications may be installed when:

- A pedestrian signal is needed to "minimize vehicle-pedestrian conflicts" or to assist pedestrians in making a safe crossing.
- Multi-phase indications may confuse pedestrians.
- A divided roadway exists and the signal timing only allows pedestrians to cross to the island during one interval.

The development of improved pedestrian warrants for traffic signals must address two separate issues. These issues include: (1) warrants for installing new traffic signals (with pedestrian signal indications) based on pedestrian considerations, as provided in Warrant 3 (Minimum Pedestrian Volume) and Warrant 4 (School Crossing); and (2) warrants for installing new pedestrian signal indications (i.e., WALK/DONT WALK signals) where traffic signals already exist. This study focuses primarily on the former issue, that is, warrants for installing new traffic signals particularly as they relate to the Minimum Pedestrian Volume Warrant (Warrant 3).

The basic Minimum Pedestrian Volume Warrant requires 600 vehicles per hour entering the intersection (both approaches of the major street) for each of any 8 hours of an average day and also 150 or more pedestrians per hour during the same period on the highest volume crosswalk. Many traffic engineers and researchers have argued that the current MUTCD pedestrian volume warrant is inappropriate. Pedestrian volume requirements are considered too high by most traffic experts to have any practical applicability. In order to provide pedestrian signalization, many traffic engineers must rely on their own engineering judgment when selecting locations for pedestrian signal installations. This has created inconsistencies between regions of the country and often between state and local agencies concerning the conditions under which pedestrian signals are necessary.

This chapter reviews and critiques the existing MUTCD warrant and other relevant guidelines reported in the literature and develops a revised warrant, more suitable for practical application in the U.S. The background and analysis leading to the recommended warrant are presented in the following sections.

## Review of Existing and Proposed Warrants

The review of the Pedestrian Volume Warrant involved conducting a comprehensive literature review to identify and critique other studies which have been conducted relative to this warrant. In particular, studies which recommended warrants to replace the current MUTCD warrant were analyzed to determine their validity. A critical analysis of the MUTCD warrant and the other proposed pedestrian volume warrants was helpful in the development of a new warrant.

The 1978 MUTCD warrant for Minimum Pedestrian Volume (Warrant 3) is satisfied when 600 or more vehicles per hour enter an intersection (both approaches of the major street) for each of any 8 hours of an average day along with 150 or more pedestrians per hour during the same period crossing the highest volume crosswalk of the major street. For a divided highway, 1,000 vehicles or more per hour are required. Where the traffic speed exceeds 40 mph (64 kph) or in isolated communities (less than 10,000 population), the requirements are reduced to 70 percent of those stated above. At midblock locations, the warrants are the same, provided that the crosswalk is not closer than 150 feet (45 m) to another established crosswalk [1]. A more detailed discussion of the MUTCD warrants relative to pedestrians and the historical development of these warrants can be found in Appendix D.

In 1967, a study was conducted by Box for the Signal Committee of the National Joint Committee on Uniform Traffic Control Devices [2]. The purpose of the study was to review warrants for traffic signals and suggest considerations and numerical values for warrants. A warrant was recommended in this study which required a minimum of 60 pedestrians per hour for one hour (or for two 30-minute periods) and also an average of 60 seconds of mean delay per pedestrian for one of the two 30-minute periods. This warrant is based upon the premise that pedestrians are subjected to greater exposure to injury compared to motor vehicles, and that motorists have the added protection from inclement weather.

A study was conducted for NCHRP Project 3-20 entitled "Traffic Signal Warrants" in 1976 by Lieberman, King, and Goldblatt [3]. A warrant based primarily on pedestrian delay considerations was presented in this study (in graphical form) for undivided streets and divided streets. A minimum of 100 pedestrians per hour are required to meet this warrant. Minimum required traffic volumes for undivided and divided streets were 500 and 1,000 vehicles per hour respectively [3].

A delay based warrant was presented by King in 1977 [4] that uses an exponential arrival distribution model, originally developed by Tanner in 1951 [5]. Based on a 30-second assumed acceptable level of pedestrian delay and a 60-second level of maximum tolerable pedestrian delay, pedestrian signal warrants were prepared graphically for undivided highways and divided highways. It should be noted that Tanner's delay model is based on the assumption of random arrival of vehicles, whereas vehicular arrivals in most urban intersections are not likely to be random in nature. Thus, the validity of using the Tanner delay model for developing warrants at urban intersections may be questioned.

The <u>Canadian Traffic Signal Installation Warrant</u> developed in 1966 is based on pedestrian volumes and delays. The specific warrant is as follows [6]:

"a. Pedestrians on an average must wait in excess of 60 seconds before being able to cross the main street in safety;

b. The number of pedestrians wishing to cross is at least 60 per hour;

c. The conditions specified in (a) and (b) exist for any four not necessarily continuous hours of a normal day;

d. The intersection or other location is suitable for signalization;

e. The nearest existing or proposed signal installation is more than 1,000 feet (300 m) away."

The existing delay to pedestrians should be determined by a study at the location in question.

The Canadian warrant is similar to the warrant recommended by Box in terms of the minimum required pedestrian volumes (60 per hour) and mean delay per pedestrian (60 seconds). However, the Canadian warrant requires those conditions for 4 hours, compared to two 30-minute periods in the Box recommended warrant.

In developing these warrants, pedestrian signal warrants in a number of other countries were reviewed, including those in Great Britain, Ireland, Australia, and New Zealand. This review revealed a considerable amount of variation in the pedestrian volume (ranging between 90 pedestrians per hour to 600 pedestrians per hour) for warranting a signal. It was also noted that some countries have attempted to use delay-based warrants, although pedestrian volume has always been the major criterion in this regard. A detailed discussion of these and other warrants are given in Appendix E.

## Critique of the MUTCD Warrant

To evaluate the existing pedestrian signal warrant, five specific criteria were selected, as follows:

Criterion 1 - Appropriateness and reasonableness of the warrant.
Criterion 2 - Complexity of the warrant.
Criterion 3 - Data requirements.
Criterion 4 - Flexibility of the warrant.
Criterion 5 - Acceptability of the warrant by practicing traffic engineers.

The intent of Criteria 1 was to see if this warrant is realistic in terms of how many locations are likely to meet the warrant under real world conditions. Criteria 2 was designed to test the amount of time and expertise needed to apply the warrant. Criteria 3 considered the data burden associated with the warrant and Criteria 4 was designed to determine if it can account for most of the real world situations, if it offers ways to reduce required data collection efforts, or if it simplifies the analysis procedure. Lastly, Criteria 5 was a combination of the preceding four, but it was deemed important in its own right, since the traffic engineering community is ultimately responsible for using the warrants to justify signal installations.

As a pedestrian signal warrant was tested using each of the criteria, a rating of "Excellent", "Good", "Fair", or "Poor" was assigned depending on how well the criteria are satisfied. The assignment of these ratings was largely subjective, but much objective information was used to apply them. Also, it is important to note that the criteria were not all assigned equal importance. For example, the appropriateness of a warrant was certainly the most important criteria, since if the warrant was totally inappropriate (Criteria 1), then the other criteria would not really matter.

### Criterion 1 - Appropriateness and Reasonableness of the Warrant

The 1978 MUTCD Pedestrian Volume Warrant (Warrant 3) was evaluated using the five criteria discussed above. In terms of appropriateness and reasonableness (Criterion 1), several sources were used to judge the warrant. Discussions were held with approximately 70 traffic engineers throughout the country, who overwhelmingly indicated that the current MUTCD Pedestrian Volume Warrant is unrealistically high. In most cities, few or no traffic signals can be justified based on the Pedestrian Volume Warrant. This was confirmed by data obtained in the NCHRP 3-20 survey of current practices, which showed that only 171 out of 12,780 traffic signal installations (1.3 percent) were based on the Pedestrian Volume Warrant [3]. Also, a majority of the available studies, which reviewed the Pedestrian Volume Warrant, recommended or suggested warrants which were much lower (easier for a signal to be justified) than the MUTCD warrant in terms of required numbers and duration of pedestrian volumes.

To gain further insight into the reasonableness of the MUTCD Pedestrian Volume Warrant, an analysis was conducted of the daily pedestrian volumes which would be required to warrant a pedestrian signal. Pedestrian and traffic volume data were compiled for 388 locations from Chicago, Richmond, and Detroit. The 12-hour pedestrian counts were obtained from the local agencies for each site. A computer program was used to develop the distribution of the pedestrian volumes from the 1st highest hour to the 12th highest hour. The highest hourly pedestrian volume (in percent) was found for each location (regardless of when that hour occurred), and an average of the 388 highest hourly pedestrian volume percentages was computed to be 16.5 percent of the 12-hour total volume. The average of the second highest hourly volume was 13.3 percent of the 12-hour volume, and so on, as shown in Table 28. By using data from 24-hour pedestrian counts taken in Seattle [7], it was found that the peak 12-hour pedestrian volume (7:00 a.m. to 7:00 p.m.) represented 86 percent of the 24-hour pedestrian volume. The percent volumes were then adjusted to 24-hour volumes for CBD, OBD and fringe areas, residential areas, and all locations combined (Table 28).

It can be seen that for an average intersection, the 8th highest hourly pedestrian volume would represent about 5.5 percent of the 24-hour pedestrian volume. Also, the cummulative total of the highest 8 hours of pedestrian volume represent about 70.5 percent (14.2 + 11.4 + ...... + 5.5) of the 24-hour total (Table 29). A plot of the distribution of pedestrian volume from the 1st to the 12th highest volume hours is given in Figure 3.

One must consider the following information to assess the implications of the MUTCD warrant relative to the above data.

- A minimum of 150 pedestrians per hour are required on the highest volume approach (which is only one leg of an intersection) for any 8 hours of an average day. Thus, the 8 highest hours of an average day must each have at least 150 pedestrians per hour, even though that 8th highest hour only represents 5.5 percent of the daily (24-hour) pedestrian volume.

- To meet the MUTCD Minimum Pedestrian Volume Warrant (150 pedestrians per hour for the 8th hour), the pedestrian volumes corresponding to the first seven highest hours can also be computed, based on the pedestrian volume distribution given above. For

Table 28. Distribution of pedestrian volumes by the 12 highest hourly volumes.

| Hour | CBD Locations | | OBD and Fringe Locations | | Residential Locations | | All Locations | |
|---|---|---|---|---|---|---|---|---|
| | Percent of 12-Hour | Percent of 24-Hour | Percent of 12-Hour | Percent of 24-Hour | Percent of 12-Hour | Percent of 24-Hour | Percent of 12-Hour | Percent of 24-Hour |
| Highest | | | | | | | | |
| Hour | 18.6 | 16.0 | 16.0 | 13.8 | 16.4 | 14.1 | 16.5 | 14.2 |
| 2nd | 14.7 | 12.6 | 13.1 | 11.2 | 13.2 | 11.4 | 13.3 | 11.4 |
| 3rd | 11.9 | 10.2 | 11.2 | 9.6 | 11.2 | 9.6 | 11.3 | 9.7 |
| 4th | 9.7 | 8.3 | 9.8 | 8.4 | 9.9 | 8.5 | 9.8 | 8.4 |
| 5th | 8.8 | 7.6 | 8.9 | 7.7 | 8.9 | 7.7 | 8.9 | 7.7 |
| 6th | 7.9 | 6.8 | 8.2 | 7.1 | 7.9 | 6.8 | 8.6 | 7.4 |
| 7th | 6.8 | 5.8 | 7.3 | 6.3 | 7.2 | 6.2 | 7.2 | 6.2 |
| 8th | 6.0 | 5.2 | 6.6 | 5.7 | 6.4 | 5.5 | 6.4 | 5.5 |
| 9th | 5.2 | 4.5 | 5.9 | 5.1 | 5.8 | 5.0 | 5.7 | 4.9 |
| 10th | 4.5 | 3.9 | 5.3 | 4.5 | 5.1 | 4.4 | 5.0 | 4.3 |
| 11th | 3.6 | 3.1 | 4.3 | 3.7 | 4.4 | 3.8 | 4.3 | 3.7 |
| 12th | 2.3 | 2.0 | 3.4 | 2.9 | 3.6 | 3.0 | 3:0 | 2.6 |
| Totals | 100.0 | 86.0* | 100.0 | 86.0* | 100.0 | 86.0* | 100.0 | 86.0* |
| Number of Intersections Used | 43 | | 77 | | 268 | | 388 | |

* The remaining 14 percent of the daily pedestrian volume occurs during nighttime hours (between 7:00 p.m. and 7:00 a.m.).

Table 29. Summary of projected hourly volumes required to meet The Pedestrian Volume Warrant.

| Hours of the Day | Percent of Daily 24 Hour Pedestrian Volume | Projected Hourly Volume |
|---|---|---|
| 1st Highest Hourly Volume | 14.2 | 387 |
| 2nd Highest Hourly Volume | 11.4 | 311 |
| 3rd Highest Hourly Volume | 9.7 | 264 |
| 4th Highest Hourly Volume | 8.4 | 229 |
| 5th Highest Hourly Volume | 7.7 | 210 |
| 6th Highest Hourly Volume | 7.4 | 202 |
| 7th Highest Hourly Volume | 6.2 | 169 |
| 8th Highest Hourly Volume | 5.5 | 150 |
| 9th Highest Hourly Volume | 4.9 | 134 |
| 10th Highest Hourly Volume | 4.3 | 117 |
| 11th Highest Hourly Volume | 3.7 | 101 |
| 12th Highest Hourly Volume | 2.6 | 71 |
| 13th-24th Highest Hourly Volumes | 14.0 | 382 |
| Total of 24-Hour Volume | 100.0 | 2,727 |

Note: The hourly volume for each row was based upon the control total of 150 hourly pedestrians comprising 5.5 percent of the total during the 8th highest hour.

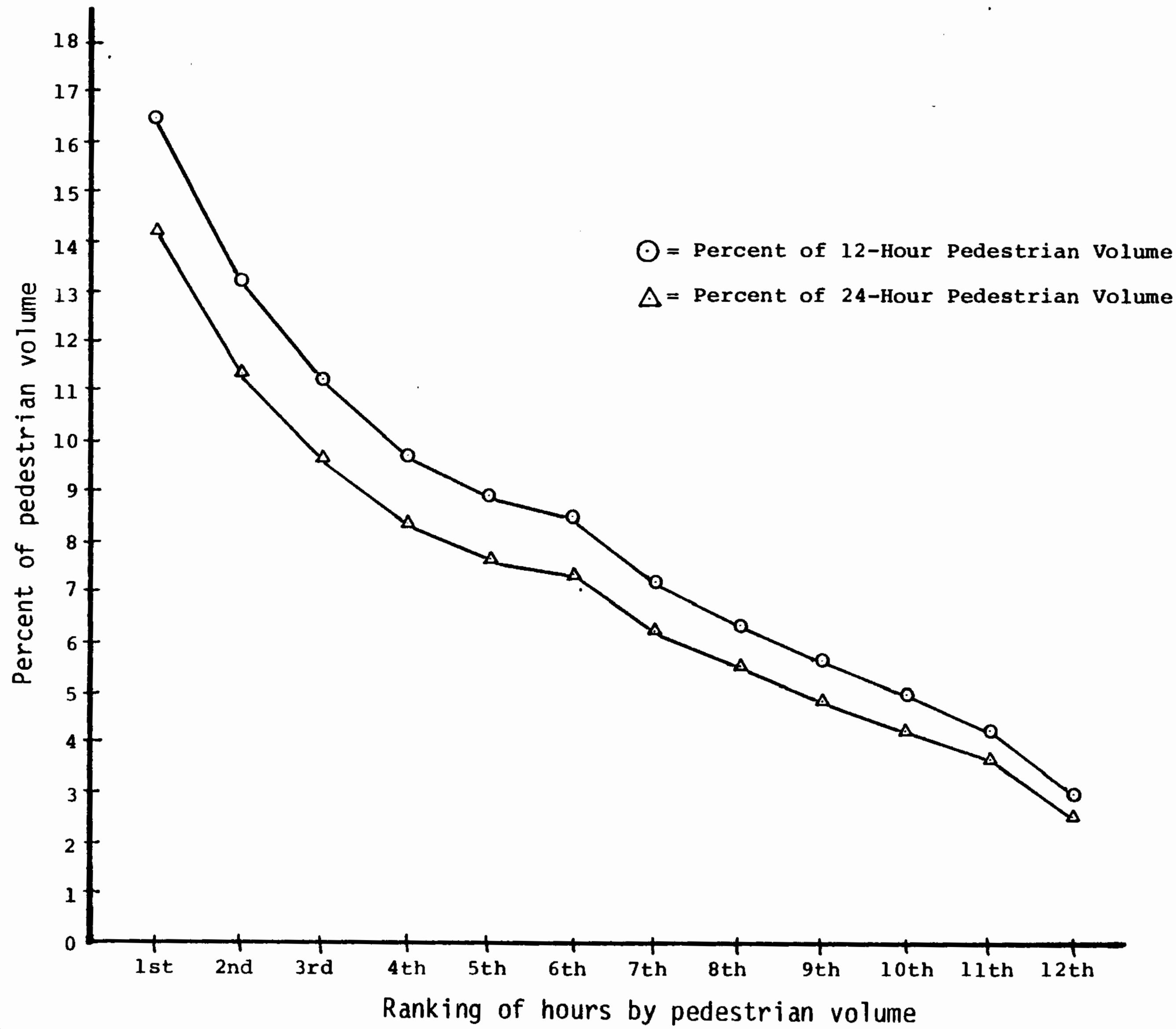


Figure 3. Distribution of pedestrian volume by hour for the 12 highest hourly volumes.

example, if the 8th highest hour requires 150 pedestrians and corresponds to 5.5 percent of the daily traffic, the pedestrian volume for the highest hour (for an urban intersection with an average volume distribution) can be computed as:

$$\frac{14.2 \text{ percent}}{5.5 \text{ percent}} \times 150 = 387 \text{ pedestrians in the highest hour}$$

- Likewise, for the 2nd highest hour (11.4 percent of the daily volume) of the day, the volume is calculated as 311 pedestrians per hour. For each of the other time periods, the hourly pedestrian volumes can be computed in a similar fashion. As Table 29 shows, a minimum of about 2,727 pedestrians per day are required on the highest volume approach in order to satisfy the Minimum Pedestrian Volume Warrant, assuming an average hourly distribution of pedestrian volumes.

- The next step is to equate the 2,727 pedestrians on the highest volume approach to the equivalent total pedestrian volume on all 4 approaches for an average 4-legged intersection. If pedestrian volumes crossing all four approaches were equal, then 25 percent of the pedestrian volume would cross each leg. However, such uniform crossing volumes do not usually exist in the real world. An analysis was conducted of 101 intersections selected at random from Chicago and Washington, D.C. to determine what percent of volume actually corresponds to the highest volume leg for a typical 4-legged intersection. By computing the percent of the 1st, 2nd, 3rd, and 4th highest legs (based on pedestrian volume), the following percentages were found:

| | Mean | Standard Deviation | Percent of Total |
|---|---|---|---|
| Highest Volume Leg | 0.360 | 0.079 | 36.0 |
| 2nd Highest Leg | 0.265 | 0.037 | 26.5 |
| 3rd Highest Leg | 0.214 | 0.040 | 21.4 |
| 4th Highest Leg | 0.161 | 0.043 | 16.1 |
| Total of 4 Legs | 1.00 | | 100.0 |

Based on these percentages, the highest volume crossing represents about 36 percent of the total intersection volume. Note that the standard deviation of each average value is quite low, which indicates low deviation from the mean. It is, therefore, possible to convert the minimum required daily volume of 2,727 for the highest volume leg to an equivalent total intersection volume for an average 4-legged intersection as:

$\frac{2,727}{0.36} = 7,575$ pedestrians per day (all 4 approaches of a 4-legged intersection)

The equivalent pedestrian volume for a 3-legged intersection would be less than 7,575. For a midblock crossing, the previously calculated value of 2,727 would be the expected minimum daily pedestrian volume corresponding to the MUTCD Minimum Pedestrian Volume Warrant.

The above analysis was conducted to illustrate the high daily volume of pedestrians (about 7,600 at a typical 4-legged intersection) which is necessary to meet the Minimum Pedestrian Volume Warrant. Such high volumes are quite unrealistic, except in a very small number of locations such as in large urban areas. A plot of the average pedestrian volumes (in percent) by time of day are given in Figure 4, as determined from the data base.

To further test the MUTCD warrant for appropriateness and reasonableness, an analysis was conducted to determine the percent of signalized locations which would meet the 8-hour MUTCD pedestrian volume warrant in two large urban areas. Chicago and Washington were chosen, since 10 to 12 hours of pedestrian volume data were readily available for intersections in those cities. Of 422 intersections chosen in the two cities, 355 (84 percent) had sufficient vehicle volumes (600 per hour for 8 hours), but only 34 (8 percent) had sufficient pedestrian volumes (150 or more on the highest volume crosswalk for any 8 hours) to meet the warrant. An additional 78 intersections (19 percent) could have met a 4-hour pedestrian volume warrant (150 per hour on highest volume approach for at least 4 hours). A total of 156 of the signalized intersections (37 percent) had sufficient pedestrian volumes for at least one hour per day. A summary of the data is given in Table 30. It appears that virtually all of the signals in the sample must have been installed based on other signal warrants.

Based on all available information discussed above, it was determined that the pedestrian volume requirements (150 per hour on the highest volume approach for each of eight hours) of the MUTCD Minimum Pedestrian Volume Warrant is unrealistically high. It is not appropriate for most cities, and should be revised to allow for signal installations at locations with daily pedestrian volumes considerably below the current requirements. Thus, the MUTCD warrant was rated as poor based on Criterion 1.

## Criterion 2 - Complexity of the Warrant

The pedestrian volume warrant was next evaluated on Criterion 2, which involved the complexity of using a warrant. The warrant is applied by simply reviewing the hourly volumes of pedestrians and vehicles and

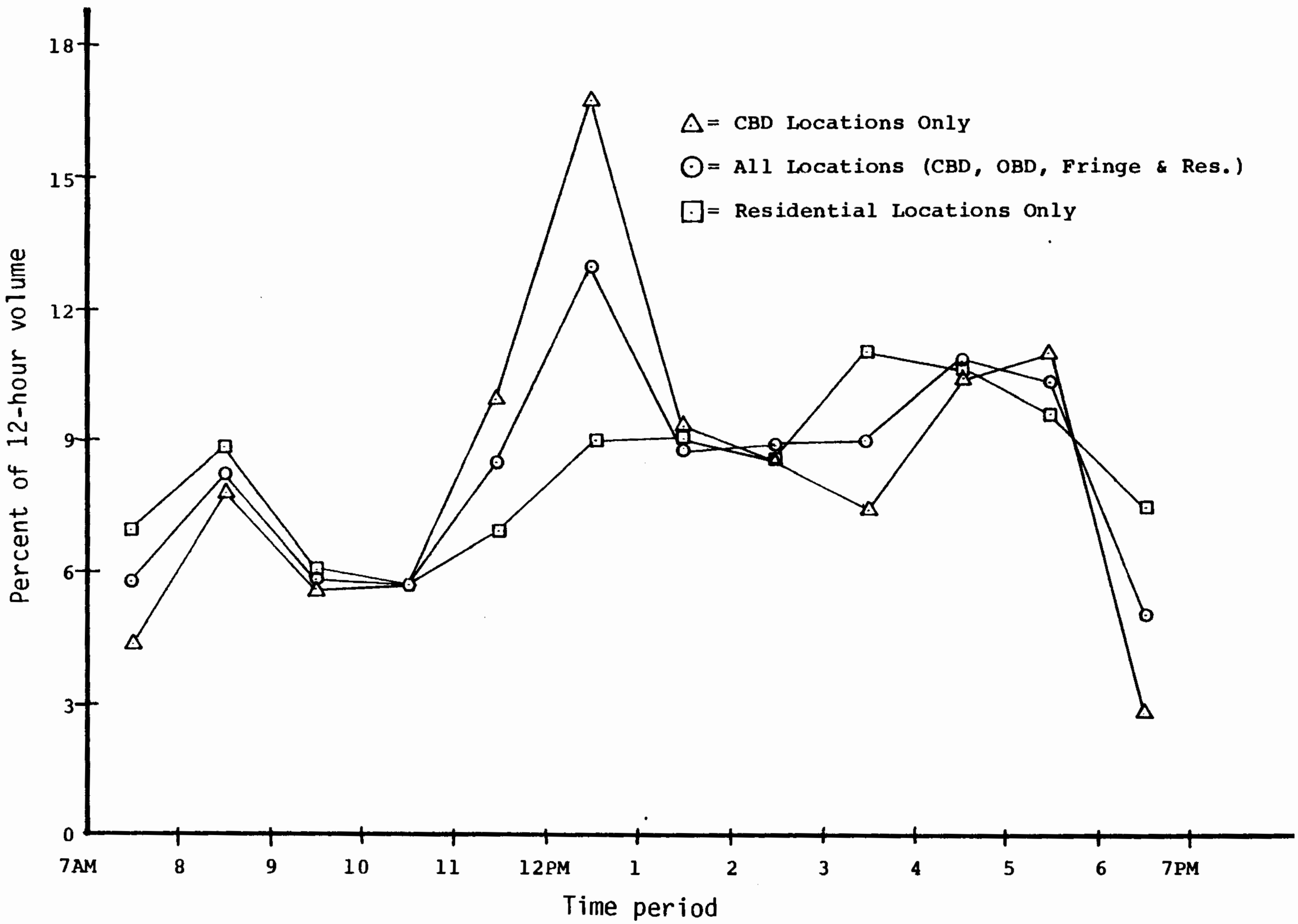


Figure 4. Distribution of pedestrian volume by time of day.

Table 30. Number of intersections meeting various vehicle and pedestrian volume criteria for different data collection periods.

| City | Total Number of Intersections | Number of Locations Meeting the Vehicle Warrant (Percent) | Number of Locations Meeting Pedestrian Volume Warrant (Percent) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 60 per hour | | | | 100 per hour | | | | 150 per hour | | | |
| | | | 1 HR | 2 HR | 4 HR | 8 HR | 1 HR | 2 HR | 4 HR | 8 HR | 1 HR | 2 HR | 4 HR | 8 HR |
| Chicago, IL | 236 | 212 (90%) | 217 (92%) | 202 (86%) | 174 (74%) | 136 (58%) | 176 (75%) | 161 (68%) | 126 (53%) | 83 (35%) | 89 (38%) | 63 (27%) | 36 (15%) | 12 (5%) |
| Washington, D.C. | 186 | 143 (77%) | 126 (68%) | 112 (60%) | 80 (43%) | 57 (31%) | 97 (52%) | 81 (44%) | 61 (33%) | 36 (19%) | 67 (36%) | 56 (30%) | 42 (23%) | 22 (12%) |
| Total | 422 | 355 (84%) | 343 (81%) | 314 (74%) | 254 (60%) | 193 (46%) | 273 (65%) | 242 (57%) | 187 (44%) | 119 (28%) | 156 (37%) | 119 (28%) | 78 (19%) | 34 (8%) |

determining whether eight of those hours meet the criteria. An adjustment of 70 percent is made in these minimums for average traffic speeds of over 40 mph (64 kph). This is a relatively uncomplicated procedure to utilize, so the MUTCD Minimum Pedestrian Volume Warrant was rated as good based on Criterion 2.

## Criterion 3 - Data Requirements

The data requirements (Criterion 3) are somewhat difficult to meet for most cities. In order to find 8 hours of pedestrian and vehicle volumes which meet the warrant, a city traffic engineer may need to collect volume counts for 8 to 12 hours in a single day, since the peak 8 hours may not always be known until the data has been collected. In contacting over 70 major U.S. cities, only Detroit and Chicago were found to routinely conduct 10- to 12-hour pedestrian volume counts. Washington, D.C., had 10-hour pedestrian volume counts available at most of signalized intersections. Richmond, Virginia, had more than 100 12-hour counts, and Seattle had collected some 24-hour sidewalk counts with a mechanical counter a few years ago. Although peak hour pedestrian counts are more common, a few cities collected occasional manual pedestrian counts of 1- to 3-hours duration. Except for those cities, most of the other cities contacted collected little or no pedestrian volume data.

Based on these findings, it is not realistic to expect cities to utilize their limited manpower to collect large amounts of additional data in order to use a signal warrant (particularly given the present fiscal resources which have forced many city and state agencies to reduce their existing staffs). Therefore, a poor rating was assigned to the MUTCD warrant for Criterion 3.

## Criterion 4 - Flexibility of the Warrant

Criterion 4 involves the flexibility of the warrant in accounting for a range of highway and traffic conditions. The current warrant allows a 70 percent reduction adjustment in the minimum criteria for high speed locations greater than 40 mph (64 kph) or small towns of less than 10,000 population. Also, the minimum traffic volume is 1,000 vehicles per hour instead of 600 vehicles per hour, if a raised median exists. However, except for this possible one-time adjustment of 70 percent, the 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 (40 versus 56 kph)
- Street width - undivided streets of 20 feet versus 50 feet (6 versus 15 m)
- Vehicle volumes - volumes of 700 per hour versus 2,000 per hour
- Vehicle arrival rates - random versus traffic queues
- Pedestrian walking speeds - 2.5 feet per second versus 4 feet per second (0.8 versus 1.2 m/s)

Therefore, the MUTCD Minimum Pedestrian Volume Warrant was rated as fair/poor according to Criterion 4.

Criterion 5 - Acceptability of the Warrant by Practicing Traffic Engineers

Criterion 5 is the acceptability of the warrant by practicing traffic engineers in the U.S. As discussed previously, the current MUTCD Minimum Pedestrian Volume Warrant fares poorly in the opinion of many traffic engineers in the U.S. (based on discussions with traffic engineers in numerous large cities) due to its unrealistically high required pedestrian volume and large amount of required data.

In summary, the following represent the ratings of the MUTCD Minimum Pedestrian Volume Warrant according to the five criteria:

| Criterion Number | Criterion Description | Rating |
|---|---|---|
| 1 | Appropriateness and reasonableness | Poor |
| 2 | Complexity | Good |
| 3 | Data requirements | Poor |
| 4 | Flexibility | Fair/Poor |
| 5 | Acceptability by traffic engineers | Poor |

## Development of a Revised Warrant

The review of various warrants in North America and abroad identified a number of different concepts which served as the basis for warrants including minimum pedestrian volume, delay, weighting of pedestrians with vehicular traffic, and others. It was felt that a warrant based on a minimum volume of pedestrians for a specified 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.) provided the best approach for a revised warrant. With this in mind, the development of a revised warrant was initiated to take into account the following factors:

- Duration of required time
- Number of legs for warrant
- Minimum pedestrian requirement
- Criteria for gaps or pedestrian delay

### Duration of Required Time

The duration of required time should be somewhere between 1 hour and 4 hours, since volume data for less than one hour is likely to be unreliable due to large fluctuations associated with short periods of time. Also, collection of citywide pedestrian volume data for more than 4 hours per site is simply not practical in most cities. 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 1-hour warrant, a 2-hour warrant, or a 4-hour warrant. Locations could warrant a signal based on one high peak hour per day or on lower pedestrian volumes occurring during 4 hours (i.e., 1 morning peak hour, 1 noon peak hour, and 2 afternoon peak hours). Based on known distributions of pedestrian volumes by hour, it would be quite simple to develop equivalent pedestrian volume levels for any time period discussed earlier. The requirement of pedestrians per hour would be higher for the 1-hour warrant than the 2-hour warrant.

## Number of Legs for Warrant

The next issue involves the number of intersection legs which should be specified as part of the warrant. Of all the studies reviewed, the MUTCD warrant is the only one that requires the pedestrian volume to be on the highest volume approach, which can cause problems. For example, assume that intersection A has 140 pedestrians per hour on each of four approaches during the 8th highest hour of an average day. Location B has 155 pedestrians per hour on one approach and 20 per hour on each of the other three approaches. Both intersections have traffic volumes over 600 per hour for 8 hours. In all, Intersection A has 560 pedestrians per hour compared to 215 per hour on Intersection B. However, Intersection B meets the MUTCD warrant for a traffic signal, (with 215 pedestrians per hour) but Intersection A does not (with 560 per hour).

This example may be exaggerated to illustrate a point, but this high requirement for volumes on one intersection approach is one of the problems of the current MUTCD Minimum Pedestrian Volume Warrant. It is therefore recommended that the warrant be expressed in terms of pedestrians crossing the highest volume street (or the total volume crossing at a midblock location).

## Minimum Pedestrian Requirement

Some of the existing or commonly recommended minimum pedestrian volumes and time periods are shown in Table 31. In order to further review the consequences of these various pedestrian warrants, they were applied to a sample of 388 signalized intersections in Chicago and Washington, D.C. (where 10 or more hours of pedestrian volume data were available). Three warrants were selected for testing purposes, including:

- 60 pedestrians per hour (major street) - as proposed by Box and is the current Canadian criterion [2,6].
- 100 pedestrians per hour (major street) - as proposed in studies by King and NCHRP 3-20 [3,4].

Table 31. Summary of existing and recommended minimum pedestrian volumes and data collection periods for several warrants.

| Source(s) | Minimum Pedestrians Per Hour | Time Period | Equivalent Pedestrian Volumes per Day* (rounded to nearest 10) |
|---|---|---|---|
| Box [2] | 60 | Two 30-Min Periods | 470 |
| Canada [6] | 60 | 4 Hours | 710 |
| NCHRP 3-20 [3] King [4] | 100 | 4 Hours | 1,190 |
| MUTCD [1] | 150 | 8 Hours | 4,360 (at midblock or two intersection legs crossing the two highest legs of the intersection) |

*Based on pedestrian volume distributions by hour. All volumes are for total pedestrians crossing the major street either at midblock or intersection locations.

- 150 pedestrians per hour (highest volume leg), as per the MUTCD warrant [1].

Each location was tested to see how many hours that it would meet each pedestrian volume criterion. The results illustrated in Figure 5 show the percent of intersections meeting various pedestrian volume criteria for different hours in a day. For example, the MUTCD warrant was met for one hour or more by about 38 percent of the locations, but was met for 8 hours by only about 5 percent of the locations. The warrant of 60 pedestrians per hour was met for at least one hour per day by over 80 percent of the locations and by at least 4 hours for over 60 percent of the locations. These percentages, of course, are for locations with mostly moderate to high volumes of traffic and pedestrians with existing traffic signals. Therefore, the percentage meeting the warrants would likely be much lower for a random sample of unsignalized locations.

The purpose of this illustration is to show the relative effect of the length of time and hourly pedestrian volume criteria on the number of traffic signals which would meet various warrants. Notice that the percent of locations meeting any pedestrian volume level decreases drastically as the required time period is increased (i.e., high negative slope of the curves). The vertical difference between curves illustrates the effect of different pedestrian hourly volume criteria on the percent of locations which may satisfy a particular warrant.

To add further insight into an appropriate pedestrian volume criterion, a branching analysis was conducted on 1,289 signalized intersections as discussed in Chapter I, to determine what traffic and roadway variables explain the most variation in pedestrian accident experience. Also, it was hoped that the analysis would provide insights on the traffic and geometric factors which are important in pedestrian accident experience. The branching program was run using the Statistical Analysis System (SAS) program package. The program looks for the dichotomous split on the predictor variable (i.e., pedestrian volume, traffic volume, street width, etc.) which best predicts the dependent variable (i.e., pedestrian accidents). The program operates under the principle of least squares and subdivides the data set into mutually exclusive subgroups [8].

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, compared to 0.553 for 680 locations above 1,200 pedestrians per day. It should be mentioned that the 1,289 intersections in the analysis had traffic signals, so the break-point of 1,200 pedestrians per day from this analysis may not necessarily be the exact same break-point for pedestrian accidents at nonsignalized intersections. If one assumes that the addition of a traffic signal improves pedestrian safety (due to creating artificial

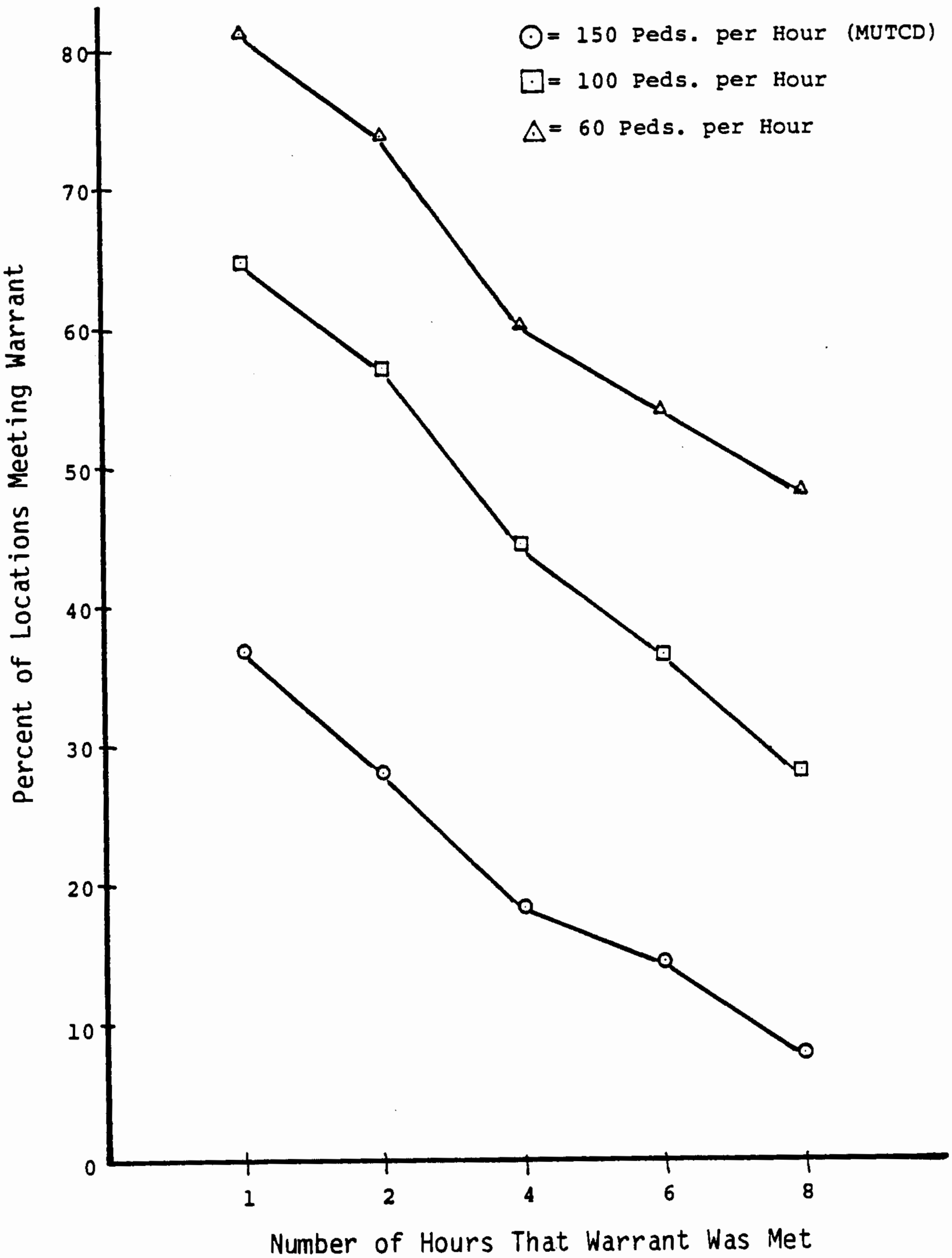


Figure 5. Percent of locations meeting various pedestrian volume warrants: Based on 422 signalized locations in Chicago, Illinois and Washington, D.C.

gaps in traffic for pedestrians to cross), then the critical break point for unsignalized intersections would logically be something less than 1,200 pedestrians per day. Thus, a value of 1,200 would be a conservatively high value. Many might argue, however, that in areas of poor signal compliance, the addition of a traffic signal could actually reduce pedestrian safety, due to the high incidence of pedestrian and motorist signal violations. Obviously, it would be very difficult to define the optimal pedestrian break point value for all roadway situations, but 1,200 pedestrians per day may be a reasonable approximation based on available data. It should also be mentioned that adding a traffic signal commonly results in an increase in some types of motor vehicle accidents, such as rear-end accidents, but often reduces right-angle accidents.

A daily pedestrian volume of 1,200 at 4-legged intersections corresponds to a pedestrian volume of 750 crossing the major street (two highest volume legs), based on (36.0 percent + 26.5 percent) 62.5 percent of pedestrians crossing the highest volume legs. Based on hourly pedestrian distributions, this would convert to the following volumes for the 1st, 2nd and 4th highest hourly volumes:

| Volume Period | Equivalent Pedestrian Volume (nearest 10 pedestrians) |
|---|---|
| 24-Hour Volume | 750 |
| 1st Highest Hour | 110 |
| 2nd Highest Hour | 90 |
| 4th Highest Hour | 60 |

The minimum pedestrian volume for the 4th highest hour corresponds to the Canadian pedestrian volume criterion of 60 pedestrians per hour for four hours. It would be stricter than the Box warrant, which requires 60 pedestrians per hour for each of two 30-minute periods [2]. The pedestrian volume criterion would be less strict than the 100 pedestrians per hour for four hours, as required by King and NCHRP 3-20 [4,3]. For shorter time periods of 2 hours or 1 hour, pedestrian volumes of 90 per hour and 110 per hour would be required, respectively.

## Criteria for Gaps or Pedestrian Delay

A pedestrian signal warrant must consider not only pedestrian volumes, but also the time available for pedestrians to cross the street (i.e., 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. The number of adequate gaps in traffic can be determined based on field surveys, the ITE method [9], the method recommended by Neudorff [10], or other methods.

A gap-based warrant of less than 60 acceptable gaps per hour is currently the school crossing warrant prescribed in the MUTCD. This gap-based criterion actually accounts for site-specific combinations of street width, pedestrian walking speed, vehicle speed, traffic volume, and traffic arrival patterns. It is, therefore, conceptually appealing as well as practical to use along with a pedestrian volume criterion for a limited time period per site.

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

1. 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 any two hours, or

   110 or more during the peak hour

2. In addition to a minimum pedestrian volume of those stated above, the number of adequate gaps in the traffic stream should be less than 60 per hour during the same period when the pedestrian volume criterion is satisfied.

3. The crossing must be at least 150 feet (45 m) from another established crosswalk and 300 feet (100 m) from an adjacent signal.

## Signal Warrants for Elderly and Handicapped

The current MUTCD does not have special provisions in its pedestrian signal warrants to account for an abnormally high percentage of elderly or handicapped pedestrians. Recent efforts have been made to develop special warrants for such locations. A report of the ITE Committee 4A-6 in 1983 provided some proposed signal warrants to address the special needs of the elderly and handicapped [9]. The ITE study report recommends consideration of a midblock pedestrian signal if all of the following conditions are met:

"1. Location is at least 150 feet (45 m) from a protected crossing.

2. At least 50 senior or disabled pedestrians* cross per hour for four or more hours of an average day.

3. Less than 30 gaps of appropriate length per hour, or less than seven (7) gaps of appropriate length** per 15-minute period of any hour, for the same (period) as in paragraph two (2)."

* All to be of walking speed 2.5 ft/sec (0.8 m/sec) or less.

** Appropriate gap length assuming walking speed 2.5 ft/sec (0.8 m/sec)

The calculation of adequate gaps recommended in the study was similar to the school crossing criteria described in the ITE Traffic Engineering Handbook [9].

In Seattle, Washington, a special set of criteria was recently proposed for installing traffic signals to accommodate the disabled and senior citizens. The warrant was written to provide different minimum pedestrian volumes and gaps for 2-lane and 4-lane crossings. The pedestrian volume requirement is 100 (12.5 per hour) and 200 (25 per hour) elderly or handicapped pedestrians for an 8-hour period for 4-lane and 2-lane streets, respectively. In addition, there must be less than 60 adequate gaps in vehicular traffic during the hour of peak pedestrian volume [13].

A recommended signal warrant for elderly and handicapped pedestrians should include considerations for minimum volumes of pedestrians and the number of acceptable gaps per hour. Alternate time periods could also be used for the warrant, and the minimum required pedestrian volumes should be less than the ones used for adult crossing locations. Also, not more than four hours of data collection should be required. Based on the recommended Minimum Pedestrian Volume Warrant (for the general pedestrian population) and considerations of signal warrants for the elderly and handicapped from several sources, the following special warrant was recommended to be included as a part of the Minimum Pedestrian Volume Warrant:

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

1. The location is at least 150 feet (45 m) from a protected crossing.

2. 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, or

3. During the hour that pedestrian volume is the highest, there must be less than 60 adequate gaps. Walking speeds of 2.5 ft/sec (0.8 m/sec) should be used when computing adequate gap time.

4. 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 may be provided to alert motorists to use added caution.

## School Crossing Warrant

A warrant for installing traffic signals in school zones based on pedestrian considerations was first introduced in the 1971 edition of the MUTCD and later included in the 1978 manual. The warrant is met when "the number of adequate gaps in the traffic stream during the period when children are using the crossing is less than the number of minutes in the same period" [1]. Thus, if children are crossing the street for 15 minutes in each of the morning and afternoon periods (total of 30 minutes), a traffic signal would be warranted if less than 30 adequate gaps existed in traffic during that 30-minute period. Procedures for measuring adequate gaps are described by ITE [12].

A detailed analysis was conducted of the School Crossing Warrant in terms of the five criteria discussed previously. In summary, the School Crossing Warrant was considered to be appropriate for most real-world conditions, is relatively simple to apply, and requires a reasonable amount of data collection. The warrant was determined to be flexible, since it is based on the number of adequate gaps and allows for consideration of many traffic and geometric site conditions. Finally, the School Crossing Warrant was found to be accepted by most traffic engineers that were contacted during this study. The MUTCD School Crossing Warrant was recommended for continued use as currently stated. Further details of the evaluation of the MUTCD School Crossing Warrant can be found in Appendix E.

## Accident and Combination Warrants

Of the eight traffic signal warrants, the ones that are most closely related to pedestrian considerations are Warrant 3 - Minimum Pedestrian Volume and Warrant 4 - School Crossing. However, there are two other warrants which also involve some consideration to pedestrians. These include Warrant 6 - Accident Experience and Warrant 8 - Combination of Warrants.

The Accident Warrant is satisfied when the following four conditions are met [1]:

"1. Adequate trial of less restrictive remedies with satisfactory observance and enforcement has failed to reduce the accident frequency; and

2. Five or more reported accidents, of types susceptible to correction by traffic signal control, have occurred within a 12-month period, each accident involving personal injury or property damage to an apparent extent of $100 or more; and

3. There exists a volume of vehicular and pedestrian traffic not less than 80 percent of the requirements specified either in the Minimum Vehicular Volume Warrant, the Interruption of Continuous Traffic Warrant, or the Minimum Pedestrian Volume Warrant; and

4. The signal installation will not seriously disrupt progressive traffic flow."

As can be seen, reference is made to the Minimum Pedestrian Volume Warrant in Item 3. As discussed earlier, the current MUTCD Minimum Pedestrian Volume Warrant is unrealistically high, and even 80 percent of the requirement would translate to 120 pedestrians per hour on the highest volume approach for 8 hours of the day, which is still not realistic for most locations. It is far more likely that Item 3 in the Accident Warrant will be met by 80 percent of the vehicular volume warrant or the continuous traffic warrant. This provision of 80 percent of the Minimum Pedestrian Volume Warrant would be much more meaningful and feasible if the pedestrian volume requirement for the Minimum Pedestrian Volume Warrant (Warrant 3) is lowered to a more realistic level, as recommended earlier.

One other point should also be made concerning the Accident Experience Warrant. It Item 2 above, five or more accidents per year are required "of types susceptible to correction by traffic signal control...". It is highly unlikely that 5 pedestrian accidents in a 12-month period could be used to justify a traffic signal. For example, a study by Robertson showed that out of 2,665 intersections in Washington, D.C., and Oakland, California, only one percent of the locations had as many as 6 pedestrian accidents in 3-year period (2 per year) [14]. The location with the most accidents of the 2,665 intersections had 12 in a 3-year period (4 per year). Similar distributions of pedestrian accidents were also found for 1,297 signalized intersections used for the accident analysis conducted in Chapter I. In this study the intersections were selected independently of accident experience. The following is a summary of the number of pedestrian accidents for intersections in that sample:

| Number of Pedestrian Accidents Per Intersection Per Year | Number of Intersections (Percent) |
|---|---|
| 0 | 515 (39.7) |
| 0.01 to 0.50 | 462 (35.6) |
| 0.51 to 1.00 | 215 (16.5) |
| 1.01 to 1.50 | 62 ( 4.8) |
| 1.51 to 2.00 | 29 ( 2.2) |
| 2.01 to 2.50 | 10 ( 0.8) |
| 2.51 to 3.00 | 2 ( 0.2) |
| 3.01 to 3.50 | 1 ( 0.1) |
| 3.51 to 4.00 | 1 ( 0.1) |
| Total | 1,297 (100.0) |

According to this summary of signalized intersections in 15 cities throughout the U.S., 91.8 percent of the locations have an average of 1 or fewer pedestrian accidents per year. The overall average was about 0.37 pedestrian accidents per year per location. This information illustrates the fact that pedestrian accidents alone are highly unlikely to be used to justify a traffic signal at a location based on the Accident Experience Warrant. However, if one pedestrian accident and four vehicle accidents susceptible to correction by a traffic signal (such as angle accidents) occurred, this may be interpreted as fulfilling the Accident Experience Warrant requirements.

The Combination of Warrants (Warrant 8) states as follows [1]:

> In exceptional cases, signals occasionally may be justified where no single warrant is satisfied but where two or more of Warrants 1, 2, and 3 are satisfied to the extent of 80 percent or more of the stated values.
>
> Adequate trial of other remedial measures which cause less delay and inconvenience to traffic should precede installation of signals under this warrant.

The Accident and Combination Warrants appear to be reasonable as stated, except for one problem. The requirement of 80 percent of the pedestrian volume in the Accident and Combination Warrants is unrealistic, since the Minimum Pedestrian Volume Warrant (Warrant 3) is too high. If Warrant 3 is modified to the recommended level, then the wording of the Accident and Combination Warrants would be adequate.

## Pedestrian Signal Indications

Most of the previous discussion has dealt with warrants for installing traffic signals (along with pedestrians indications) based on pedestrian considerations in order to create artificial gaps in traffic to facilitate pedestrian crossings. The discussion of signal warrants in the MUTCD is included in Section IV-C Warrants. Section IV-D of the MUTCD is entitled "Pedestrian Signals", which provides guidelines on when to install pedestrian signal indications (i.e., WALK/DONT WALK or equivalent symbolic messages) at locations where traffic signals already exist. Also, under Section IV-D is a discussion of specific design requirements for the signal hardware, the location of the pedestrian heads, and the planning of pedestrian intervals and phases.

A review was made of the conditions under which pedestrian signal indications shall be installed. These include [1]:

- When a signal meets the Minimum Pedestrian Volume or School Crossing Warrant.

- When an exclusive pedestrian phase is provided.

- When vehicular indications are not visible to the pedestrian.

- At established school crossings.

All of these requirements were judged to be valid, and they should remain a part of the MUTCD.

Three other conditions are given in the MUTCD when pedestrian signals <u>may</u> be installed [1]:

- When pedestrian volume requires a clearance interval to minimize vehicle pedestrian conflicts.

- When multi-phase indications are confusing.

- When pedestrians cross part of a street during a particular interval.

The first of these three statements ("when pedestrian volume requires a clearance interval to minimize vehicle-pedestrian conflicts") is so general that it may be used to require pedestrian signals at all signalized intersections within a city or at no signalized intersections in the same city, depending on its interpretation. It would be desirable to provide more specific examples of where pedestrian signals are needed. Efforts could be made to conduct additional research on the subject and contact traffic engineers and learn of their successes and failures regarding the use of pedestrian signals.

The second and third criteria relating to pedestrian signal installation (i.e., when multi-phase indications are confusing or when pedestrians cross part of a street during a particular interval) are more specific than the first criterion. They both serve a useful purpose and should be left in the MUTCD.

The use of pedestrian indications in general has not been shown to result in significant safety benefits when concurrent timing is used, as discussed in Chapter I. Exclusive pedestrian intervals result in significantly lower pedestrian accident rates than either concurrent timing or signalized locations with no pedestrian indications although pedestrian and traffic delay increases from the use of exclusive timing. Discretion should be used by traffic engineers instead of arbitrarily installing pedestrian signals at all traffic signalized locations.

## Pedestrian Actuation Devices

Pedestrian actuation (push-button) devices have been installed extensively in many cities. The 1978 MUTCD specifies conditions for use of pedestrian-actuated control, as follows [1]:

"1. When pedestrian signals are not warranted (sec. 4D-3) in conjunction with a traffic actuated signal but where occasional pedestrian movement exists and there is inadequate opportunity to cross without undue delay, pedestrian detectors shall be installed and operated as prescribed in sections 4D-6 and 7.

2. When pedestrian signals are not otherwise warranted but a pedestrian movement exists which would not have adequate crossing time during the green interval, pedestrian signals and detectors shall be installed and operated as prescribed in sections 4D-6 and 7.

3. When pedestrian signals are warranted and installed in conjunction with a traffic actuated signal, the operation should follow the patterns described in sections 4D-6 and 7".

The use of pedestrian actuated signals is also prescribed under the School Crossing Signal Warrant for non-intersection crossings.

To gain insight into the problems and possible solutions relative to pedestrian actuation devices, field observations were conducted at 64 intersection approaches in Southeastern Michigan (i.e., Detroit and Ann Arbor area). For each approach, information was collected relative to the use of the push-button, the signal violation and compliance rate, and the ages of the pedestrians who crossed. At a few of the sites, information was also collected on pedestrian-vehicle conflicts which resulted at the sites.

Of 1,014 total pedestrians, 65.9 percent were observed starting to cross during the flashing or steady DONT WALK interval. The violation rate ranged from a low of 34 percent at one site to a high of 71 percent at another. Only 51.3 percent of all crossing pedestrians pushed the button to actuate the signal.

Low utilization of pedestrian actuation devices was also observed in a FHWA study by Petzold and Nawrocki of approximately 2,700 pedestrians crossing at intersections in six cities [15]. Observed push-button use ranged from 1 to 35 percent of the crossing pedestrians with an average rate of 16 percent.

Based on a review of crossing patterns and site characteristics at the data collection sites as well as information from the literature, the following problems were identified relative to pedestrian actuation devices:

- Many pedestrian actuation devices are hidden from view of the pedestrian or located out of reach, such as on telephone or luminaire poles as far as 10 to 20 feet (3 to 6 m) from the crosswalk.

- Signing for many actuation devices is confusing to pedestrians, since it does not clearly indicate which direction corresponds to the actuation device.

- Many pedestrian actuation devices are timed to only provide a WALK interval after a wait of one minute or more (i.e., at the end of a signal cycle). This increases pedestrian delay and discourages their use or gives the impression that they are inoperative.

- The push-button devices are used infrequently because pedestrians either do not understand how they operate, or do not choose to push them and wait for the WALK indication.

- Many of the push-button devices are inoperative or operate only during certain hours which has led to confusion on the part of the pedestrian and their general non-use.

- When pedestrian actuated signals are used at a midblock location, motorists become conditioned to always expect the green light. Thus, when the push-button is activated and the traffic signal goes to red (and a WALK signal is given) there is a likelihood that the motorist may inadvertently run the light. This can create a dangerous environment, since the pedestrian believes that he is protected.

- Too often, pedestrians push the button and then cross the street before they get the WALK phase. Then, traffic is stopped needlessly, causing unnecessary vehicle delay.

Although numerous problems currently exist with pedestrian-actuated signals, the basic concept is desirable, since traffic would only be required to stop when one or more pedestrians are present to activate the signal. Based on the violation rates and rates of pedestrians using the actuation devices, there is evidence to suggest that the following improvements would be beneficial to locations with pedestrian actuation devices.

- Repair and maintain the actuation devices to insure their proper operation. This will gradually improve pedestrian respect and use of the devices.

- Make the actuation devices more responsive to pedestrians. The signal could be timed to provide a waiting time of 30 seconds or less to the pedestrian after the button is activated. In many cases, the signal could be timed to complete the current phase or possibly shorten the phase and then provide for the pedestrian interval. For constant pedestrian arrivals, the WALK phase could be provided once per cycle if activated frequently.

- A sign should be installed with each push-button device to explain their proper use. Signs designating specific streets (i.e., PUSH BUTTON TO CROSS GRANGER STREET) could also be used, as currently exist in numerous locations in Ann Arbor, Michigan.

- Provide a device to indicate to the pedestrian that the activated signal is working and they will soon have the WALK interval. For example, a light could come on when the button is pushed (as recommended in section 4D-6 of the MUTCD).

- If a pedestrian device is designed to only work for specific periods of the day (i.e., 10 a.m. to 4 p.m.), there should be a sign accompanying the actuation device explaining this. A sign might read PUSH BUTTON IN OPERATION FROM 10 AM TO 4 PM. This type of sign would let pedestrians know that the actuation device is not broken during the other periods of the day and should gradually improve pedestrian respect of these devices. An alternate recommendation is to eliminate the use of actuation devices which are not in operation at all times of the day (or during operation of the traffic signal).

## Conclusions and Recommendations

The purpose of this chapter was to evaluate existing MUTCD warrants related to pedestrian signals and actuation devices by examining existing literature and operational practice. If the existing MUTCD warrants were found to be inadequate, new warrants were to be developed.

The MUTCD Minimum Pedestrian Volume Warrant was found to be unacceptable in terms of its: (1) appropriateness to the real-world conditions; (2) data requirements; (3) flexibility; and (4) acceptability to practicing engineers. Based on all available literature and existing pedestrian signal warrants, a number of different warrant concepts were examined. The preferable concept was found to be one which incorporates a minimum pedestrian volume per hour and a number of adequate gaps per hour. Based on an in-depth study of hourly pedestrian volume distributions and an analysis of data at 1,297 intersections, a revised Minimum Pedestrian Volume Warrant was recommended.

The existing Minimum Pedestrian Volume Warrant is so unrealistically high that little possibility exists in many cities for warranting a traffic signal based on pedestrian considerations. This indicates that the needs of pedestrians may be injustly ignored, and that pedestrians are too often considered as merely a hinderance to traffic flow in our society.

The recommended new Minimum Pedestrian Volume Warrant would result in more traffic signals being installed, since additional traffic signals would be warranted based on the less stringent warrant. The additional number of warranted signals nationwide is not precisely known. However, it is expected that at most locations meeting the new pedestrian volume warrant, a traffic signal will already exist, having been warranted by one or more of the other traffic signal warrants. A check of the number of newly warranted signals should be conducted in several cities to determine its effect on new signal installation costs.

A supplementary warrant was recommended to consider the special needs of elderly and handicapped pedestrians. The existing School Crossing Warrant was found to be appropriate for U.S. school locations and was recommended for continued use.

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# CHAPTER III - EFFECTIVENESS OF PEDESTRIAN SIGN AND SIGNAL ALTERNATIVES

One of the major pedestrian safety problems in the U.S. today is the ineffectiveness and confusion associated with pedestrian signal indications. Pedestrians in many cities largely ignore pedestrian signals due to a lack of understanding or respect for the devices. In fact, violations of the DONT WALK message have been found to be higher than 50 percent in many cities [1].

The lack of effectiveness of pedestrian signal indications in commanding respect, improving compliance, and reducing pedestrian accidents could be due to several reasons. This chapter, however, addresses the following two deficiencies with pedestrian signals:

- Misunderstanding and confusion by pedestrians regarding the meaning of the solid and flashing <u>DONT WALK</u> indication.

- Misunderstanding and confusion by pedestrians regarding the meaning of the solid and flashing <u>WALK</u> indication.

A steady illuminated DONT WALK message means that a pedestrian shall not enter the intersection in the direction of the indication, according to the 1978 edition of the Manual on Uniform Traffic Control Devices [2]. The flashing DONT WALK indication is a clearance interval intended to inform pedestrians not to start crossing the street, but to complete their crossing if they have already begun. Many pedestrians do not distinguish the difference in meaning between the flashing and the steady DONT WALK indications. Other pedestrians tend to treat the DONT WALK message as only advisory, or ignore it and cross at their own discretion. The accident analysis conducted in the first phase of this project indicates that the pedestrian had violated the signal message in a majority of pedestrian accidents at signalized intersections.

The lack of compliance, resulting either from the failure to understand the signal message or from a purposeful disrespect of the messages, is the main problem associated with pedestrian signals. This is aptly described by Jennings et al. who studied pedestrian behavior in 1977 at a number of signalized locations in the City of Portland, that had experienced a large number of pedestrian accidents [3]. The authors stated that:

> "Numerous pedestrians do not obey the DONT WALK signals. Numerous pedestrians do not look in the presence of either a WALK or DONT WALK signal before crossing the street. Moreover, the pedestrians who do not stop also do not look. In short, there are a reasonable number of pedestrians who do not appear to assess the traffic situation before crossing the street".

A second problem with pedestrian signal indications involves the flashing WALK indication. The flashing WALK indication is used in some jurisdictions to inform pedestrians that vehicles may be turning across their path. In areas using the flashing WALK, the solid WALK is generally used to designate a protected pedestrian crossing interval during which vehicles are not permitted to turn across the crosswalk. However, many jurisdictions do not use the flashing WALK for the following reasons: (1) many pedestrians do not understand the meaning of the flashing WALK; (2) their signal display hardware is not easily adaptable to provide a flashing WALK display; or (3) utilization of a flashing WALK at one location would necessitate utilizing the flashing WALK at all other appropriate locations which would cause a financial hardship to the agency. In areas which do not use a flashing WALK, the solid WALK display is used regardless of whether the pedestrian interval is protected or not.

Confusion commonly occurs since many pedestrians either do not know the meaning of the flashing WALK, or believe that any WALK indication (whether flashing or steady) means that they need not look around for cars or use caution. The danger occurs when a motor vehicle runs the red light or turns across a crosswalk without yielding to pedestrians. Although a pedestrian has the right-of-way, he should also exercise caution whenever crossing the street, since he is the one most susceptible to injury or death in the event of an collision with a motor vehicle.

It is believed that these basic problems related to pedestrian signals can be addressed, in part, by signal alternatives. These alternatives include new signal devices, modifications of existing devices, the use of supplemental devices to enhance the function of the signal, and means to promote improved understanding of the signals. Two areas in which signal alternatives are most likely to be effective include:

- Pedestrian clearance alternatives - to replace or supplement the flashing DONT WALK indication.
- Alternatives to indicate potential conflicts - to replace or supplement the flashing WALK indication.

In addition, several other factors must also be considered in efforts to enhance pedestrian safety at signalized intersections. These factors include:

- The level of enforcement of pedestrian compliance to the signal messages,
- The level of enforcement of vehicle compliance to the pedestrian's right-of-way,
- The level of education (i.e., in schools, over the radio and television, etc.) or public awareness regarding the meaning of pedestrian signals, pedestrian and vehicle laws, and pedestrian behavior, and

- Changes in the physical roadway environment through traffic engineering or geometric improvements which offset the lack of pedestrian safety.

Figure 6 illustrates how the pedestrian signal alternatives might address specific pedestrian problems at signalized intersections. For example, pedestrians who understand and comply with pedestrian signals still need to be alerted to turning vehicles. Pedestrians who violate signals either do not understand their meaning or simply choose to disregard them. For pedestrians who intentionally violate the signals, police enforcement and/or improved pedestrian signs or signals (more demanding of respect) may be appropriate.

As a part of this study, a comprehensive literature and current practice review was completed to identify alternatives for indicating the clearance interval and warning of potential conflicts (presented in Appendix F). Subsequently, a range of candidate signal alternatives were developed, priority ranked, and the most promising alternatives selected for field testing. The selected alternatives were fabricated and field tested at selected intersections in five cities. Before and after analyses of pedestrian compliance and pedestrian-vehicle conflicts were used to evaluate each alternative. This chapter documents the results of these tests and provides recommendations for the most promising pedestrian signalization alternatives.

## Alternative Pedestrian Clearance Indications

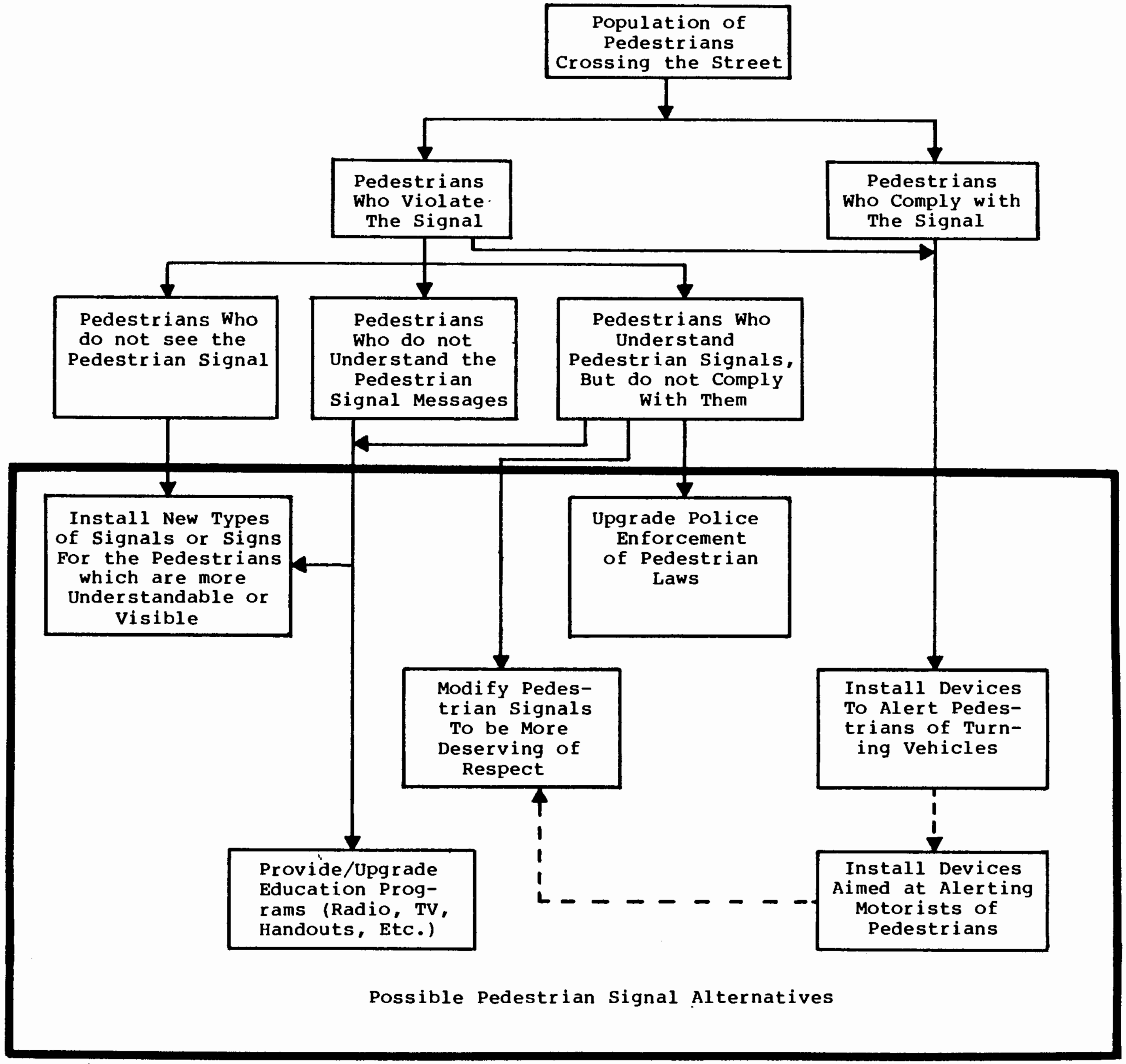
Alternative pedestrian clearance indications were developed by the project team members after a comprehensive review of MUTCD guidelines, current practices, and available literature. Subsequently, feasible alternatives were selected for field testing. The following sections discuss the findings and results of these efforts to develop alternatives for the pedestrian clearance indication.

### MUTCD Guidelines

The signal display most commonly used to indicate the pedestrian clearance interval is the flashing DONT WALK message. The 1978 version of the MUTCD defines the flashing DONT WALK as follows [2]:

> "The DONT WALK indication, while flashing, means that a pedestrian shall not start to cross the roadway in the direction of the indication, but that any pedestrian who has partly completed his crossing during the steady WALK indication shall proceed to a sidewalk, or to a safety island."

The 1963 and 1971 versions of the MUTCD were essentially the same in terms of definition of the clearance interval and use of the flashing DONT WALK for the pedestrian clearance interval [4,5].




← - - - These alternatives can be used in conjunction with alternatives aimed at the pedestrian.

Figure 6. Breakdown of pedestrian signal alternatives as they relate to the pedestrian problem.

In terms of design requirements for pedestrian signal heads, the MUTCD states that they should be readable during both day and night hours, shall be rectangular in shape, and shall consist of either WALK and DONT WALK word messages or the symbolic messages. The DONT WALK indication shall be Portland orange, and the WALK message shall be white. For crossings of 60 feet (18 m) or less, the letter size shall be at least 3 inches (7.6 cm) high and symbols shall be at least 6 inches (15.2 cm) high. For crossings greater than 60 feet (18 m), the letter size should be at least 4.5 inches (11.4 cm) high and the symbols should be at least 9 inches (22.9 cm) high. As a safety precaution, if the word DONT of the DONT WALK messages goes off through an electrical or mechanical failure, the word WALK of the DONT WALK will also remain off. The pedestrian signal faces shall be mounted between 7 and 10 feet (2.1 and 3.0 m) above the sidewalk level with the DONT WALK message directly above the WALK indication [2].

The 1978 MUTCD states that provisions for the clearance interval (flashing DONT WALK) should be as follows [2]:

> "The duration should be sufficient to allow a pedestrian crossing the street to leave the curb and travel to the center of the farthest lane before opposing vehicles receive a green indication (normal walking speed is assumed to be 4 feet per second). On a street with a median at least 6 feet in width, it may be desirable to allow only enough pedestrian clearance time on a given phase to clear the crossing from the curb to the median. In the later case, if the signals are pedestrian-actuated, an additional detector shall be provided on the island."

<u>Development of Candidate Clearance Alternatives</u>

A careful review was conducted of past research and current practices relative to pedestrian clearance indications, as summarized in Appendix G. Approximately 22 different alternatives for depicting the clearance intervals were proposed by various members of the project team for further consideration. These alternatives were refined with inputs from discussions with FHWA officials and pedestrian signal and safety experts.

Descriptions of these alternatives were compiled and these include:

- Description (movement, color, message, size and location).
- Sketch or drawing of the alternative.
- Past use of the alternative.
- Justification for use.
- Potential advantages.
- Potential disadvantages.
- Estimated cost of installation.
- Estimated cost of maintenance and operation.

The full descriptions of each alternative are provided in Appendix G. A brief description of each of these alternatives is presented in Table 32.

Table 32. List of candidate experimental devices to indicate the clearance interval for pedestrians.

| Category | Device | Description | Selected Yes/No | Comments |
|---|---|---|---|---|
| Education | 1. Educational Campaign | Radio, newspaper and/or television ads to explain the meaning of the flashing DONT WALK indication. | No | Could be very expensive to implement and extremely difficult to evaluate. |
| | 2. School Education Program | Brief presentations designed primarily for school children, senior citizen groups or other safety/community organizations. | No | Intended for the highest risk groups. Difficult to provide adequate and continuous coverage and difficult to evaluate. May not have an impact on a vast majority of pedestrians. |
| | 3. Driver Education Program | Educating drivers by including pedestrian signal information in drivers manuals and in examinations when applying/renewing driver licenses. | No | Extremely long implementation times and difficult to evaluate. Does not impact school-age children or non-drivers. |
| Sign | 4. Pedestrian Signal Explanation Sign | A sticker or small sign attached to the pedestrian signal pole or other device near the crosswalk explaining the meaning of the flashing DONT WALK and other pedestrian signal indications. | Yes | Provides continuous education to pedestrians in the vicinity of the crosswalk. Not applicable for those who cannot read (i.e., small children). |
| Signal Displays | 5. Steady DONT WALK | Use of the steady DONT WALK (or raised hand symbol) during the clearance as well as the prohibited crossing interval. | Yes | Since pedestrians do not understand the flashing message, this would be an alternative. Also could provide an extra factor of safety. |
| | 6. START/DONT START Pedestrian Signal | The use of a steady DONT START signal message during the clearance and prohibitive crossing intervals. Use START during the crossing interval. | No | Simplistic message, requires only the change of the signal lenses. The START indication may be less effective and cause of confusion. |
| | 7. WAIT/CROSS Pedestrian Signal With Push Button | An actuated signal device with a WAIT message during the clearance and prohibitive crossing intervals and CROSS during the crossing interval. The signal would be accompanied by a WAIT/CROSS signal above the push button to operate in the same manner as an elevator push button. | No | Actuation device applicable under certain conditions of vehicle and pedestrian volumes. The indications at the push button reinforces the signal message and informs the pedestrian that the actuation device is working. |
| | 8. WAIT AT CURB/ WALK Pedestrian Signal | The use of the steady DONT START signal (yellow) to indicate the clearance interval. | No | The WAIT AT CURB message is less confusing for those in the crosswalk during the clearance interval. Requires only changing the signal lenses. |

Table 32. List of candidate experimental devices to indicate the clearance interval for pedestrians (continued).

| Category | Device | Description | Selected Yes/No | Comments |
|---|---|---|---|---|
| Signal Devices | 9. 3-Head Pedestrian Signal DONT WALK/ DONT START/ WALK | A 3-head pedestrian signal with a steady DONT START signal (yellow) to indicate the clearance interval. | Yes | Provides a distinct and concise clearance message. Conforms more to the vehicle traffic signal. |
| | 10. 3-Head Signal - DONT WALK/ Yellow Ball/ WALK | A 3-head pedestrian signal using a steady yellow ball to indicate the clearance interval. | No | Simplistic and symbolic display of clearance interval. Conforms to the vehicle traffic signal indication of clearance, but could be confused with a vehicle signal. |
| | 11. One Signal Head to Display 3 Messages - DONT WALK/ Yellow Ball/ WALK | Using one pedestrian signal head to display a DONT WALK (hand) in orange, a yellow ball for clearance, and a WALK (walking man) message in white. | No | Will provide a larger single message. Technology may not be available to accomplish this economically, since pedestrian signal hardware would require total replacement. |
| | 12. 3-Head Signal - Symbolic DONT WALK/WAIT/ WALK | A 3-head pedestrian signal with an alternating flashing hand and WAIT (or DONT START) message during the clearance interval. | No | Alternative flashing symbolic and word messages during the clearance intervals will reinforce the clearance message. May be confusing. |
| | 13. 3-Head Signal - Orange/ Yellow/ White | A 3-head rectangular signal using colors to symbolize the intervals as: Orange (red) - DONT WALK; Yellow - Clearance; White (green) - WALK. | No | Simplistic color symbols in the same fashion as vehicle signal. May be confused with vehicle signals. |
| Audible Devices | 14. Audible Signal With Standard Pedestrian Signal | The use of a bell or other audible message to indicate the start of the clearance interval. | No | Audible signal reinforces the signal message and brings attention to the signal. Will be especially helpful to blind and other handicapped pedestrians. May cause noise pollution and create confusion among the pedestrians in the perpendicuar crosswalk. |
| | 15. Audible Word Message With Standard Pedestrian Signal | Use recorded word messages such as "Pedestrians DONT START Crossing on Main Street..." to reinforce the pedestrian signal messages. | No | Brings attention to the pedestrian signal indications and clarifies messages. Eliminate confusion of simple beeps or buzzes and could be helpful to blind pedestrians. May cause noise pollution or may be difficult to hear in all parts of the crosswalk and due to background noise. May be costly to implement. |

Table 32. List of candidate experimental devices to indicate the clearance interval for pedestrians (continued).

| Category | Device | Description | Selected Yes/No | Comments |
|---|---|---|---|---|
| Audible Devices | 16. Audible Signal With 3-Head Pedestrian Signal | Audible message to highlight all 3 signal messages of a 3-head pedestrian signal. | No | Brings special attention to each interval, but may be confusing to pedestrians in the perpendicular crosswalk. Particularly helpful to night impaired pedestrians. May cause noise pollution. |
| | 17. Audible Message With Pedestrian Signal On One Pedestrian Signal Head | Combination of previous alternatives to use the audible message with three distinct signal indications shown on one signal head using different colors to differentiate each message. | No | Distinct messages to indicate each interval reinforced by audible message. Audible signal brings attention to each interval and is helpful to sight impaired pedestrians. May cause noise pollution. Technology may not be available to accomplish this. |
| Other Alternatives | 18. Variable Signal Display Message | A variable signal to allow a complete message to pedestrians displayed a few words at a time. | No | Very expensive, may need to be large to allow an adequate display. Not applicable where long messages are required. May be difficult to read, not applicable to young children and poor readers. |
| | 19. Digital Countdown Clock | Pedestrian signal indicating time remaining for each interval in seconds. | No | Can be expensive. Provides needed crossing information to pedestrians. May encourage pedestrians to cross illegally when long waiting times are displayed. |
| | 20. Symbolic Countdown Device | Use of a symbolic countdown device to display time remaining during each interval. Supplements standard pedestrian signal. | No | May be expensive to install and maintain. May be confusing. May encourage pedestrians to cross during DONT WALK interval when long wait times are shown. |
| | 21. Variable Rate Flashing Indication | Use of variable rate flashing device during the clearance interval to indicate the time remaining (i.e., when flashing fast, signal ready to change). | No | Pedestrians would have to interpret the rate of flashing to determine the remaining crossing time. Confusing. Not as applicable to short intervals. |
| | 22. Pedestrian Signal Embedded In The Pavement | Use of pedestrian signal embedded in the pavement to display clearance and other pedestrian signal messages. May supplement standard signal message. | No | Many pedestrians look down while walking. This encourages pedestrians not to look up for vehicles. Not applicable when snowing and on very bright days. Impractical and costly. |

## Selection of Alternatives for Field Testing

After details of each of the alternatives were recorded, the alternatives were rated based on: (1) accident reduction potential; (2) anticipated compliance; (3) cost of implementation; and (4) ease of implementation. The criteria used were similar to those used by Robertson in the rating of signal displays in the 1977 report on "Pedestrian Signal Displays and Operation" [6].

After each alternative was rated by project team members, the results were summarized and recommendations were made to FHWA concerning the alternatives which should be considered for field testing. After reviews of the alternatives by FHWA officials, three basic clearance alternatives were selected for field testing. The three alternatives and their justification for selection were as follows:

Alternative 1: A sign attached to the pedestrian signal pole or other pole near the crosswalk which explains the meaning of the flashing DONT WALK, the solid DONT WALK, and the steady WALK (and also the flashing WALK if used). This sign was developed for both word messages and symbolic messages (Figure 7), depending on the type of pedestrian signal at a given site.

Justification For Use: This alternative will provide a means of continuous education and will remind pedestrians of the meaning of pedestrian indications. A sign placed at the intersection should provide the greatest impact to those who need it most. This alternative is low in cost (approximately $10 per sign) and would not require modifications to signal hardware. Although this type of alternative has been used to a limited degree in the past, it has never been formally evaluated.

Alternative 2: A three-section signal head with the orange DONT WALK indication, yellow DONT START indication, and white WALK indication. A photograph of this pedestrian signal is given in Figure 8.

Justification For Use: This alternative displays three distinct messages for the different crossing situations which could eliminate the confusion of the flashing DONT WALK signal display. Robertson tested the DONT START indication to replace both the flashing DONT WALK (clearance interval) and the steady DONT WALK (prohibitive interval), so pedestrians were not shown a separate clearance interval. The use of the DONT START as a separate clearance display may be more easily understood by pedestrians, since the DONT START for pedestrians would then be comparable to the amber phase of a traffic signal.

Alternative 3: A steady orange DONT WALK (or symbolic hand) indication would be shown for the clearance interval, as well as for the prohibitive crossing period, as illustrated in Figure 9.

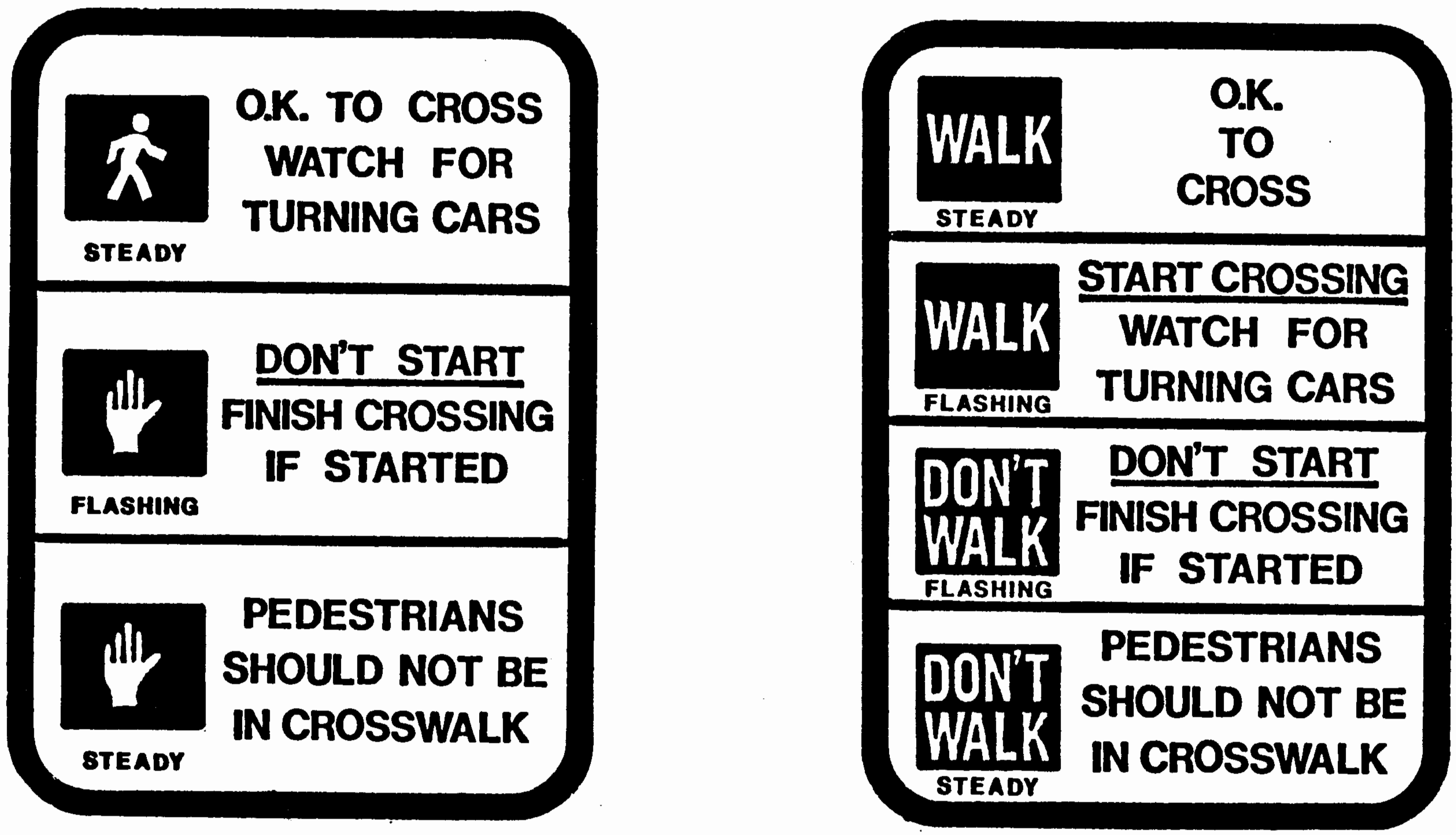



Figure 7. Symbolic and word signal explanation signs.


Figure 8. Photographs of the DONT START pedestrian signal.

| Pedestrian Interval | Before Conditon | After Condition |
| --- | --- | --- |
| Permissive |  Steady |  Flashing |
| Clearance |  Steady |  Flashing |
| Prohibitive |  Steady |  Steady |

Figure 9. Experimental displays for DONT WALK test.

Justification For Use: Since the flashing mode causes confusion, it may be preferable to only use the basic WALK/DONT WALK messages. In addition, this alternative would be less complex, since many pedestrians are confused by a flashing indication. This alternative would be low-cost and would be adaptable to existing signal hardware.

## Alternatives to Indicate Potential Conflicts

Alternatives to indicate potential pedestrian-vehicle conflicts were developed by project team members after a comprehensive review of the MUTCD guidelines, current practices, and available literature. Subsequently, feasible alternatives were selected for field testing. The following sections discuss the findings and results of these efforts relative to developing and testing alternatives to indicate potential vehiclepedestrian conflicts.

### MUTCD Guidelines

The flashing WALK indication was first introduced in the 1971 version of the MUTCD which stated [4], "The WALK indication, while flashing, means that there is a possible conflict of pedestrians with vehicles". This potential conflict is a common occurrence at locations with pedestrian WALK intervals which are concurrent with vehicle traffic. The conflict occurs when vehicles turn right or left across the path of crossing pedestrians without yielding. The problem is compounded by the fact that pedestrians often inadvertently assume that the WALK interval (either flashing or steady) insures them of absolute safety. Although pedestrians may legally have the right-of-way, motorists may often be preoccupied with other activities (looking for signs, other vehicles, etc.) and not be consciously looking out for pedestrians. This problem is worsened where pedestrian activity is random. Also, a single pedestrian may not be readily noticeable to the turning motorist, particularly with sight restrictions caused by roadway geometrics and the presence of large vehicles in the traffic stream.

The 1978 version of the MUTCD also includes a provision for the flashing WALK (in much greater detail than the 1971 MUTCD) as follows [2]:

> "A WALK indication, whether steady or flashing, means that pedestrians facing the signal indication may proceed across the roadway in the direction of the indication. In addition a WALK indication indicates one of the following:
>
> a) A steady WALK indication, when used in an area where the optional flashing WALK (see 3b below) is not used, indicates that there may or may not be possible conflicts of pedestrians with vehicles turning on a CIRCULAR GREEN indication.

b) A flashing WALK (use optional) indication means that there is a possible conflict of pedestrians with vehicles turning on a CIRCULAR GREEN indication.

c) A steady WALK indication when used in an area where the optional flashing WALK is used indicates the absence of conflicts of pedestrians with vehicles turning on a CIRCULAR GREEN indication."

According to the 1978 MUTCD, the exact interpretation of the steady WALK would require the pedestrian to know whether an optional flashing WALK is also used in the same area, as discussed in item "a" above. For example, the steady WALK indicates a protected crossing interval in some areas (i.e., areas which also use the flashing WALK), but it means that there may or may not be potential conflicts in other areas (i.e., conflicts may be present in areas where the flashing WALK is not used). In actuality, the average pedestrian is not likely to know or remember such details of pedestrian signals in an area. Thus, the purpose of the distinction between "a" and "c" is likely to be defeated.

Design requirements for the flashing WALK indication include the white WALK message or the symbolic walking man as were shown earlier (in Figure 8). As with the DONT WALK message, the size of the letters shall be 3 inches (7.6 cm) high and the size of the symbolic messages shall be 6 inches (15.2 cm) high for crosswalks of 60 feet (18 m) or less. For crosswalks over 60 feet (18 m), the size of the letter shall be 4.5 inches (11.4 cm) high and the symbolic message shall be 9 inches (22.9 cm) high. The WALK signal head shall be located between 7 and 10 feet (2.1 and 3.0 m) above sidewalk level and directly under the DONT WALK message. A minimum interval for the steady or flashing WALK message should be 4 to 7 seconds.

Development of Candidate Alternatives for Warning of Potential Conflicts

After reviewing available information relative to potential conflict indications, a total of 19 candidate alternatives were developed. These alternatives were developed using the same procedure as those developed for indicating the clearance interval. For each of the 19 alternatives, a detailed description was prepared which included:

- Description (movement, color, message, symbol, size and location)
- Sketch or drawing
- Past use
- Justification for use
- Potential advantages
- Potential disadvantages
- Estimated cost of installation
- Estimated cost of maintenance and operation

The full detailed descriptions for each candidate alternative are given in Appendix H, and a brief summary of these alternatives is given in Table 33.

Table 33. List of candidate experimental pedestrian signal devices to indicate potential conflicts with turning vehicles.

| Category | Device | Description | Selected Yes/No | Comments |
|---|---|---|---|---|
| Motorist Signs | 1. No Turn Signs | Restrict/eliminate certain hazardous turning maneuvers during times of heavy pedestrian flows or during school hours to eliminate conflicts (i.e., NO LEFT TURNS 7:00 AM - 7:00 PM). | No | Eliminates some hazardous conflicts. Inexpensive. May cause operational problems. |
| | 2. Motorist Warning Sign | Sign directed toward motorists to watch for pedestrians while turning. | No | Directed towards motorists. Relatively inexpensive. Does not force motorist action as a yield sign. May add to visual clutter. |
| | 3. Regulatory Motorist Yield Sign | Yield sign directed toward turning motorists. | Yes | Directed towards motorists. Relatively inexpensive. Requires motorist action (YIELD). May add to visual clutter. |
| | 4. Symbolic and/or Word Sign For Motorist Warning/Yield Sign | Warning/yield sign directed to motorists to stop for pedestrians while turning with symbolic pedestrian sign attached. | No | Directed toward motorists. Relatively inexpensive. Gives both symbolic and word message. May add to visual clutter. |
| | 5. Symbolic Motorist Warning Sign With Flashing Lights | Symbolic sign directed at motorists to warn of pedestrians while crossing. Used with flashing beacons or as illuminated case sign. | No | Directed toward motorists. Symbolic message may not be clear. Flashing lights may reinforce sign message. |
| Pedestrian Signs | 6. Pedestrian Signal Explanation Sign | A sticker or small sign to explain the meaning of the flashing WALK message and other signal indications. | Yes | Inexpensive. Provides continuous education to pedestrians in the vicinity of the crosswalk. Not applicable for those who cannot read (i.e., small children). |
| | 7. Pedestrian Warning Sign | Warning sign directed to pedestrians to warn of turning vehicles. Supplements pedestrian signal and located on both sides of the crosswalk facing pedestrians. | Yes | Directed toward pedestrians. Adds to visual clutter. Relatively inexpensive. |
| | 8. Pedestrian Warning Sign With Actuated Flashing Beacons | Warning signs directed to pedestrians. Pavement loop detectors used to detect approaching turning vehicles in turn lanes. Supplements pedestrian signal. | No | Directed toward pedestrians. Loop detectors are expensive. Requires special turn lanes at the intersection. Actuates when hazard present. |
| | 9. Symbolic Pedestrian Warning Signs | Symbolic warning signs directed to pedestrians to warn of turning maneuvers. Supplements pedestrian signal. | No | Directed toward pedestrians. May be confusing. Relatively inexpensive. Adds to visual clutter. |
| | 10. Remove Unnecessary Pedestrian Signals | Removal of unwarranted pedestrian signal devices where applicable. | No | Not applicable to all sites. Existing warrants not fully suitable for pedestrian signals and better guidelines are needed. Some existing pedestrian signal devices take pedestrian attention from vehicle traffic. |

Table 33. List of candidate experimental pedestrian signal devices to indicate potential conflicts with turning vehicles (continued).

| Category | Device | Description | Selected Yes/No | Comments |
|---|---|---|---|---|
| Pedestrian Signals | 11. Flashing WALK | Walk light flashes for crosswalks where vehicles may turn during WALK interval. | Yes | Used in many states and jurisdictions and recommendd in the MUTCD. Simple, low cost solution. No proven effectiveness. |
| | 12. Pedestrian Signal - WALK WITH CAUTION | Pedestrian signal display WALK WITH CAUTION during the crossing interval to warn of potential conflicts (white). | No | Directed toward pedestrians. May be confusing. Impractical from a hardware prospective due to size of word CAUTION. |
| | 13. WITH CARE Pedestrian Signal | 3-head signal displaying the message WITH CARE (steady mode) in yellow color during the WALK interval to warn of possible conflicts. | Yes | Directed at pedestrians. The WITH CARE message may not warn of the exact hazard but does denote a special problem at the crossing. |
| | 14. Pedestrian Signal Symbolic Warning Message | Symbolic message on pedestrian device to warn of potential conflicts during the WALK interval such as a yellow ball superimposed over the WALK message or walking man. | No | Directed at pedestrians. May be confusing and expensive. |
| | 15. CAUTION TURNING CARS Pedestrian Signal | 3-head signal which displays the message CAUTION TURNING CARS in a flashing or steady mode during the WALK interval to warn of possible conflicts. | No | Directed at pedestrians only. The signal provides a clear warning message during the WALK interval. Impractical for a signal message. |
| Other Alternatives | 16. Reduce Sight Obstructions At The Intersection | Eliminate obstructions to allow pedestrians/vehicles to see potential conflicts before they occur. | No | Not applicable to all intersections. May include removing parking, trees, signs, etc. near the intersection. May also improve operations and is visually more attractive. |
| | 17. Signal To Warn Pedestrians Accompanied By Motorist Yield Sign | A pedestrian signal message to warn of possible vehicle conflicts used in conjuction with a YIELD TO PEDESTRIANS sign directed at turning motorists. | No | Directed at both turning motorists and pedestrians. Requires motorists to yield. |
| | 18. Variable Message Pedestrian Signal | Pedestrian signal which displays a variable message such as "WALK/WATCH FOR TURNING VEHICLES..." during the appropriate intervals. | No | Directed at the pedestrians. Requires a large signal, and would be expensive. Problems with long messages during short intervals. May be a problem with those who cannot read well (i.e., small children). |
| | 19. Audible Word Messages | A warning message broadcast during the appropriate intervals when conflicts may occur. | No | Directed at pedestrians only. Provides a clear, concise message. May add to noise pollution. Difficult and expensive to implement. |

## Selection of Alternatives for Field Testing

Each alternative was subjectively evaluated by the project team based on: (1) accident reduction potential; (2) anticipated compliance; (3) cost of implementation; and (4) ease of implementation. The overall subjective ratings of the alternatives were made, (as discussed earlier for the clearance alternatives) and recommendations were made to the FHWA regarding alternatives to be used for field testing. The alternatives and variations selected as candidates include the following:

Alternative 1: A sign directed toward motorists informing them to YIELD TO PEDESTRIANS WHEN TURNING. The sign is a red and white, 36 by 36 by 36 inch (91 by 91 by 91 cm) downward pointing triangular shaped (shape and color of a standard YIELD sign) with a pedestrian symbol at the bottom, as shown in Figure 10.

Justification For Use: This alternative is directed toward motorists who are supposed to legally yield the right-of-way to pedestrians when turning. This alternative would be a constant reminder to drivers and have a relatively low cost. Although various agencies have used similar devices, its effectiveness has rarely, if ever, been formally evaluated, and this particular sign was designed to be conspicuous and easily understandable to motorists.

Alternative 2: A sign attached to the pedestrian signal pole which explains the meaning of the flashing WALK, the steady WALK, the flashing DONT WALK and the steady DONT WALK. This device would also be an alternative for the clearance indication, as described earlier (see Figure 7).

Justification For Use: This educational sign message provides pedestrians with the intended meaning of the pedestrian signal displays. This device is low in cost and does not require modifications to the signal hardware. The effectiveness of this device has not been formally evaluated to date.

Alternative 3: A 30 inch by 30 inch (76 by 76 cm) diamond-shaped sign with black letters on a yellow background which says PEDESTRIANS WATCH FOR TURNING VEHICLES. This sign is illustrated in Figure 11.

Justification For Use: Since many pedestrians do not obey or pay attention to pedestrian signals, it may be beneficial and considerably less expensive to use a sign reminding pedestrians to cross safely, rather than to modify the pedestrian signal.

Alternative 4: A three-section signal with the steady DONT WALK indication for the prohibitive period, a flashing DONT WALK indication for the clearance interval, and a WALK WITH CARE indication which is displayed during the WALK interval, as shown in Figure 12. Note that the standard white WALK display is used for the WALK message and a yellow WITH CARE display is added at the bottom.

Justification For Use: This alternative would provide a clear, simple warning of potential vehicle conflicts to pedestrians.

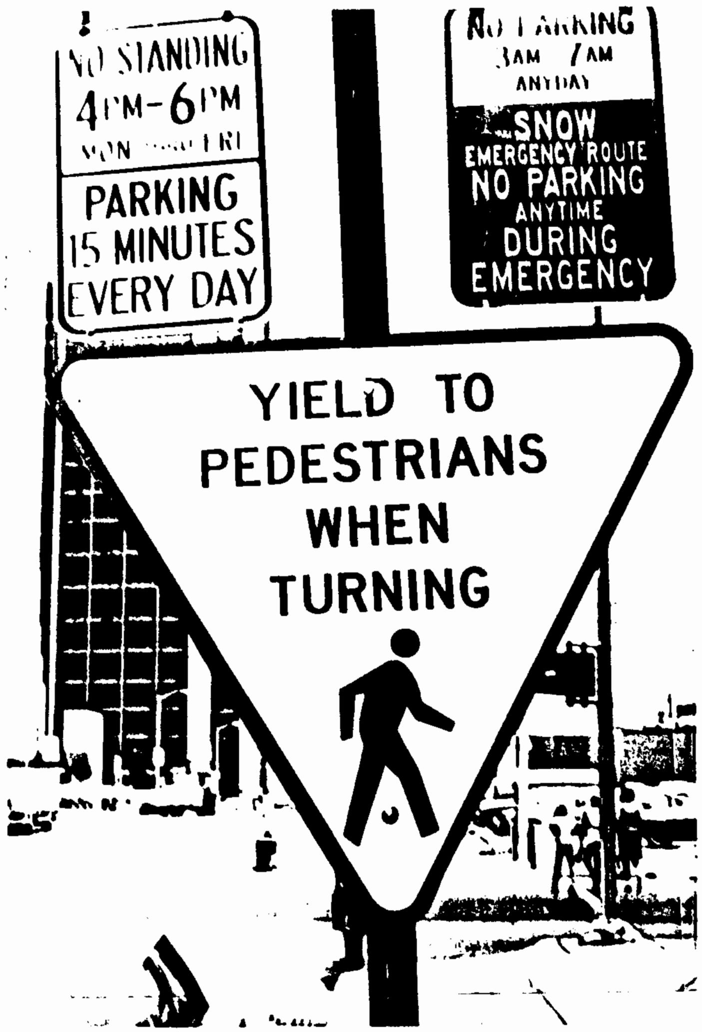



Figure 10. Photograph of the YIELD TO PEDESTRIANS WHEN TURNING sign.


Figure 11. Photograph of the PEDESTRIANS WATCH FOR TURNING VEHICLES sign.


Figure 12. Photographs of the WALK WITH CARE signal display.

Alternative 5: The use of a flashing WALK indication.

Justification For Use: This is an optional indication in the MUTCD for warning pedestrians of potential vehicular conflicts.

## Pedestrian Signalization Provisions for the Elderly and Handicapped

Several unique problems arise in terms of providing adequate signal devices for elderly and handicapped pedestrians. The elderly and a portion of the handicapped population have slower reaction times and slower walking speeds than other groups, and therefore they require longer walk and clearance intervals. Some pedestrians have visual impairments which necessitates more visible signs or an audible supplement to the signal. An auditory impairment may cause pedestrians to be less aware of oncoming or turning traffic.

In developing alternatives for the clearance interval and for pedestrian-vehicle conflicts, consideration was given to the special needs of the elderly and handicapped as discussed in detail in Appendix I. For example, the three clearance alternatives selected were:

- Alternative 1 - A sign explaining the meaning of the pedestrian signal indications.
- Alternative 2 - A steady DONT WALK signal indication.
- Alternative 3 - A three-section signal with a separate DONT START indication for the clearance interval.

All three clearance alternatives above were intended to be easier for elderly and handicapped pedestrians to understand, compared to the traditional flashing DONT WALK messages. Variations of any of these alternatives could eventually be used with an auditory tone for visually impaired pedestrians. The three-section DONT START signal indication (Alternative 2), as discussed in the ITE Committee report [7] and the sign defining the signal messages (Alternative 1) could be particularly effective with elderly and handicapped pedestrians, due to the added confusion in these groups over the flashing DONT WALK indications.

The elderly and handicapped were also considered in the development of alternatives for pedestrian vehicles conflicts. The alternatives which were selected are:

- Alternative 1 - A regulatory sign directed toward motorists informing them to YIELD TO PEDESTRIANS WHEN TURNING.
- Alternative 2 - A sign explaining the meaning of the pedestrian signal indications.
- Alternative 3 - A diamond-shaped warning sign with the words PEDESTRIANS WATCH FOR TURNING VEHICLES.

- Alternative 4 - A three-section pedestrian signal displaying a WITH CARE indication on the bottom section illuminated in yellow during the WALK interval.

- Alternative 5 - The use of a flashing WALK indication.

Alternative 1 (a sign informing motorists to yield to pedestrians) may be particularly helpful to elderly and handicapped pedestrians with slow walking speeds and/or those with auditory or perception problems who are less likely to notice and avoid a turning vehicle. The sign explaining the signal indications (Alternative 2) may be particularly informative to elderly pedestrians. The sign or signal messages which warn pedestrians of turning vehicles (Alternatives 3 and 4, respectively) may be particularly useful reminders to children (who are old enough to read) as well as to the pedestrian population in general. The effect of the flashing WALK (Alternative 5) on elderly and handicapped is unknown at this time.

## Experimental Plan

A plan was developed to evaluate the pedestrian signalization alternatives for: (1) the clearance interval; and (2) pedestrian-vehicle conflicts. This plan addressed the data needs, statistical analysis techniques, sampling requirements, site selection, and data collection procedures as described below.

### Data Needs

The evaluation of the various pedestrian signalization alternatives required information relative to: (1) pedestrian behavior (pedestrian-vehicle conflicts) and compliance of pedestrians to the signals; (2) the nature of traffic conditions at the location; and (3) the features of the location and traffic controls. The specific data needs vary somewhat by the nature of the signalization alternative being tested and its intended purpose. The following paragraphs discuss the nature of the data requirements.

The ultimate goal of each of these experimental devices was to improve pedestrian safety and reduce related accidents. However, accident data is a poor measure of effectiveness (MOE) to use for testing such devices, since:

- Many of the devices will result in relatively small or subtle changes in pedestrian or motorist behavior and resulting events. The detection of these changes based on pedestrian accidents would require testing at hundreds or thousands of locations and many years of accident data for an adequate sample size to detect any significant accident impacts.

- Pedestrian accidents are somewhat rare events at any given intersection and many pedestrian accidents are random occurrences and unrelated to the location or pedestrian signal itself. Thus, other accident surrogates (substitutes) such as pedestrian behavior or conflicts may be necessary.

At this time, no known operational MOE's have been validated as surrogates to pedestrian accidents. It must be recognized that the alternatives being tested are designed to eliminate or change certain types of pedestrian or motorist behavior which are contributory accident causes. For example, a device which reduces pedestrian signal violations will reduce the number of pedestrians in the street illegally.

Also, each pedestrian-vehicle conflict represents the beginning stages of an accident and will result in an accident unless the pedestrian and/or vehicle takes some evasive action. Thus, the use of various types of pedestrian-vehicle conflicts are logically appropriate MOE's for use in evaluating the effectiveness of various sign and signal treatments. A device which significantly reduces pedestrian violations and/or pedestrian vehicle conflicts may conceptually be regarded as having a high probability of improving pedestrian safety.

The key element in this effort was to determine whether pedestrian behavior or compliance can be altered to improve safety through various signalization alternatives. It was, therefore, necessary to collect data related to behavior and compliance. Since various pedestrian signalization alternatives were tested, with differing functions and objectives, it was necessary to determine the most appropriate MOE's.

The objectives of various alternatives are given in Table 34 along with the specific MOE's which correspond to each objective. The MOE's which were used in the analysis (as listed in Table 34) are defined as follows:

- Pedestrian-Vehicle Conflict (Behavior) Measures
    - Pedestrian Hesitation Movement (PH) - Pedestrian momentarily reverses his or her direction of travel in the traffic lane or the pedestrian hesitates in response to a vehicle in a traffic lane.
    - Aborted Crossing (AC) - Pedestrian steps off curb but later reverses direction back to the curb.
    - Moving Vehicle (MV) - Through traffic is moving through the crosswalk within 20 feet (6 m) of a pedestrian in a traffic lane.
    - Right-Turn Vehicle (RT) Interaction - Pedestrian is in the path and within 20 feet (6 m) of a right turning vehicle.
    - Left-Turn Vehicle (LT) Interaction - Pedestrian is in the path and within 20 feet (6 m) of a left turning vehicle.

Table 34. List of objectives and MOE's for the testing and evaluation of each pedestrian signal alternative.

| Type of Device | Objectives | Selected MOE's For Specific Objectives |
|---|---|---|
| Clearance Indication Alternatives (to replace the flashing DONT WALK) | 1. Improve pedestrian compliance | Pedestrians starting on clearance interval<br><br>Pedestrians starting on the prohibited interval<br><br>Pedestrians anticipating the signal |
| | 2. Reduce pedestrian-vehicle conflicts | Pedestrian Hesitation Movement (PH)<br>Run Turning Vehicle (RTV)<br>Moving Vehicle (MV)<br>Right-Turn Vehicle (RT) Interactions<br>Left-Turn Vehicle (LT) Interactions<br>Run Vehicle (RV) |
| | 3. Reduce confusion to pedestrians on the meaning of the flashing DONT WALK | Aborted Crossing (AC)<br><br>Run on Clearance (RC) |
| Alternatives to warn of Potential Conflicts with Turning Vehicles (to replace the flashing WALK) | 1. Improve pedestrian alertness in looking for turning vehicles (applies to devices aimed at pedestrians) | Right-Turn Vehicle (RT) Interactions<br>Left-Turn Vehicle (LT) Interactions<br>Run-Turning Vehicle (RTV) |
| | 2. Improve alertness of motorist for pedestrians (only applies to devices aimed at motorists) | Moving Vehicle (MV)<br>Right-Turn Vehicle (RT) Interactions<br>Left-Turn Vehicle (LT) Interactions<br>Run-Turning Vehicle (RTV) |
| | 3. Reduce pedestrian-vehicle conflicts | Pedestrian Hesitation Movement (PH)<br>Moving Vehicle (MV)<br>Run Vehicle (RV)<br>Right-Turn Vehicle (RT) Interactions<br>Left-Turn Vehicle (LT) Interactions<br>Run-Turning Vehicle (RTV) |
| | 4. Improve pedestrian compliance by alerting pedestrians of some high level of danger at the intersection (applies to devices aimed at pedestrians) | Pedestrians starting on clearance interval<br>Pedestrians starting on prohibited interval<br>Pedestrians anticipating WALK signal<br>Run on Clearance (RC)<br>Run-Vehicle (RV)<br>Aborted Crossing (AC) |

- Running Pedestrian Hazard Conflicts (or Run-Vehicle) (RV) - Pedestrian runs in a traffic lane in an effort to avoid a possible collision with a vehicle.

- Run on Clearance (RC) - Pedestrian runs at onset of clearance interval in response to the change in the signal indication.

- Run-Turning Vehicle (RTV) - Pedestrian runs in a traffic lane in response to a turning vehicle or turning vehicle potential.

- Pedestrian Violation (Compliance) Measures

  - Pedestrians starting on the clearance interval.

  - Pedestrians starting on the prohibited crossing interval.

  - Pedestrians anticipating the WALK signal (starting just prior to the end of the prohibited crossing interval).

Some of these MOE's are similar to those used by Robertson in his evaluation of pedestrian signal alternatives [7]. Other MOE's were included (i.e., interactions and aborted crossings) to provide one or more viable measures to correspond to each of the stated objectives of signalization alternatives. These MOE's represent the primary means to judge the effectiveness of each of the alternatives.

The clearance alternatives are primarily intended to improve pedestrian compliance to pedestrian signals, which should have a secondary effect on pedestrian-vehicle conflicts. Thus, the DONT START signal and pedestrian signal explanation sign, for example, were evaluated using the compliance MOE's as well as resulting conflicts. For the turning vehicle alternatives (i.e., WALK WITH CARE signal indications), the appropriate MOE's are dependent on for whom the device was intended. For example, signs aimed at the motorist (YIELD TO PEDESTRIANS WHEN TURNING sign) would not be expected to affect pedestrian compliance, but should affect pedestrian-vehicle conflicts, if motorists comply with the signs.

The PEDESTRIANS WATCH FOR TURNING VEHICLES sign was expected to have little or no effect on pedestrian compliance but should reduce vehicle-pedestrian conflicts relative to turning vehicles, if pedestrians are more aware of turning vehicles. The sign could also affect pedestrian hesitation and aborted crossings, if pedestrians are more conscious of turning vehicles as a result of the sign. The WALK WITH CARE signal indication is intended primarily to caution pedestrians to look around for turning vehicles while crossing. However, due to the general message of caution which is transmitted, it is expected that the device could also improve pedestrian compliance and other behavior, particularly for pedestrians who routinely pass through the site and are familiar with the need for caution.

A summary of the seven pedestrian signal alternatives along with the corresponding appropriate MOE's for each is shown in Table 35. Since there is a possibility that some types of MOE's will be reduced at the expense of an increase in some seemingly unrelated MOE's, each sign and signal device was also evaluated using:

- Total pedestrian violations (start on clearance, start on prohibited crossing period, and anticipate WALK).

- Conflicts with through vehicles (pedestrian hesitation, aborted crossing, moving vehicle, and run vehicle).

- Conflicts with turning vehicles (right-turn, left-turn, and running turning).

- Total conflicts (with through and turning vehicles).

Vehicular and pedestrian traffic volume conditions were also recorded at each study site. This information involved counts of vehicles and pedestrians, and vehicle turning movements. This data was required to compute proportions of pedestrian conflicts and violations and to account for the effects of varying traffic volumes. A copy of the data form used for recording data is shown in Figure 13.

In addition to volume and operational data collected before and after installation of each experimental device, site information was needed. The physical features data collected at each site was primarily used to assist in the selection of the most appropriate type of experimental device and the proper timing, location, or installation of the device. Also, site information was useful in interpreting the results of the analysis, particularly in cases where a specific device was effective at one site but ineffective at another site.

The physical information collected at each site included:

- City
- Number of lanes on each approach
- Type of signal operation (fixed-time, or actuated, etc.)
- Timing of the pedestrian and traffic signals
- Type of device tested
- Street operation (one-way or two-way)
- Location of crosswalks
- Parking, and bus stop location
- Other physical features

Details of the sites are provided in Appendix J, and data collection and coding forms are given in Appendix K. Many of the site characteristics were coded into the computer along with the volume and operational data. The resulting data file layout is given in Appendix L.

Table 35. Summary of the MOE's selected for analyzing each sign and signal alternative.

| Alternative | Purpose | No. of Sites | Violation Measures | | | Conflict Measures | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Start on Clearance | Start on Prohibited Period | Anticipate WALK Phase | Pedestrian Hesitation | Aborted Crossing | Moving Vehicle | Right Turn Pedestrian Interactions | Left Turn Pedestrian Interactions | Running Pedestrian Conflict | Run On Clearance | Run From Turning Vehicle |
| WALK WITH CARE Signal Indication | Turning Vehicle Alternative | 4 | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| YIELD TO PEDS WHEN TURNING Sign | Turning Vehicle Alternative | 4 | | | | ● | ● | | ● | ● | | | ● |
| PEDS WATCH FOR TURNING VEHICLES Sign | Turning Vehicle Alternative | 4 | | | | ● | ● | | ● | ● | | | ● |
| Steady/Flashing WALK Signal Indication | Turning Vehicle Alternative | 5 | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| DONT START Signal Indication | Clearance Alternative | 4 | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| Steady/Flashing DONT WALK Signal Indication | Clearance Alternative | 3 | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| Pedestrian Signal Expalation Sign | Clearance and Turning Vehicle Alternative | 5 | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |

● = Selected MOE's

City______________________________ Date Filmed______________ Signal Operation______________ Date Viewed______________

Location__________________________ Time Filmed______________ Walk Interval______________ Viewed By______________

Site No.______________ Reel No.______________ Weather Condition______________ Clearance Interval______________ Checked By______________

Crosswalk_________________________ Time Period______________ DONT WALK Interval______________

Device Tested_____________________ | W | FDW | DW | Cycle Length______________

| Time Interval | Time Image | | Total Time | No. of Cycles | Operational Data | | | | | | Compliance Measures | | | Behavior Measures | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Pedestrians | | Vehicles | | | | | | | | | | Turning Vehicle | | | | |
| | Start | End | | | L-R | R-L | Thru | RT | LT | RTOR | Clear-ance | Dont Walk | Antici-pate Walk | Hesita-tion | Abort Cross-ing | Moving Vehicle | RT | LT | Run Vehicle | Run Clear-ance | Run Turn |
| 1 | | | | | | | | | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | | | | | | | | | | |
| 6 | | | | | | | | | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | | | | | | | | | |
| Total | | | | | | | | | | | | | | | | | | | | | |

Figure 13. Pedestrian behavior data collection form.

## Statistical Analysis Techniques

The Z-test for proportions was selected as the statistical test. This test is used to determine if the proportion of occurrences in one group is significantly different from the proportion of occurrences in a second group. This test is applicable for continuous data (proportions), and has the following underlying assumptions [8]:

1. The distributions are binomial (i.e., either an event does or does not occur).

2. The observations are independent.

3. The sample of events is greater than 30 in each sampling period (before conditions and after conditions).

In this analysis, the events are pedestrian conflicts and violations and the opportunity for an event is a pedestrian crossing. The proportion of conflicts and violations in the before period were compared to the proportion of events in the after period at each site and a Z-value was computed. If the calculated Z-value is greater than the critical Z-value, then the difference in proportions is statistically significant. This test was further refined by conducting it separately for low, medium and high volumes of through and turning vehicles to minimize the influences of various traffic volume levels on the results.

One other consideration was whether to use "control" (or "comparison") sites to account for threats to validity to insure that any change observed in the conflicts and violations were caused by the experimental devices and not by anything else. The use of control or comparison sites is particularly important when conducting accident-based evaluations where several years elapse between data collection periods. However, when using operational measures of effectiveness (i.e., conflicts and violations) for evaluation purposes, the simple before and after experimental design is generally appropriate under most circumstances due to the relatively short period of time (a few weeks or months) between the before and after periods, as discussed by Perkins [9]. Therefore, for this analysis, the before-after experimental design was used.

## Sampling Requirements

The testing of innovative signalization devices involved a before and after measurement of pedestrian violations and conflicts. For each before and after study, the base condition or before period was selected to correspond to current MUTCD standards and the experimental conditions corresponded to the after period. For example, the before condition for the clearance alternatives was the flashing DONT WALK, which is now in use by most agencies as given in the MUTCD. The before condition for the alternatives for warning of turning vehicles was the flashing WALK in

Washington, D.C. and the steady WALK in the other cities. Washington, D.C. is the only selected city which uses the flashing WALK to warn of pedestrian-vehicle conflicts. The experimental alternatives constituted the after condition.

Estimates were made of the number of hours of data which were required for each experiment. To allow for proper use of the Z-test of proportions it is necessary to collect at least 30 conflicts or violations at each site and each time period (before and after the installation of the experimental device). Therefore, to fulfill the data requirements, it was estimated that about 2 to 6 hours of data were required for each data collection site in each of the before and after periods depending on pedestrian volume levels. Most sites were selected with moderate to high pedestrian volumes to insure sufficient samples. The actual time periods of data collection at each site were selected in part based on pedestrian volumes. For some rare events (i.e., aborted crossings) sufficient samples were not practical in many cases.

## Site Selection

Sites for the collection of data were selected to meet the following criteria:

- Have moderate to high pedestrian volumes (a minimum of approximately 1,000 per day) to insure adequate samples of events in a reasonable period of time.
- Represent typical situations and not be highly unusual in geometry or traffic control strategy.
- Have a pedestrian safety problem, since these sites are prime candidates for improvements. There is little or no justification for testing experimental devices at safe locations, since such devices are not needed, and any experimental device is almost certain to result in little or no improvement when installed at sites where there is little room for improvement.
- Have pedestrian signals (in order to compare the existing signal condition with the proposed alternative).
- Be available for the installation of innovative devices.
- Have an acceptable vantage point for mounting of video cameras or for manual data collection (i.e., pole, buildings or other structure near the intersection).
- Be appropriate for the type of device tested. For example, the clearance alternatives are most appropriate at sites with moderate to high levels of pedestrian violations and long crossing dis-

tances. Alternatives designed to reduce turning vehicle conflicts should be tested at sites with moderate to high volumes of pedestrians and turning vehicles.

Some variation was desired in region of the country and in type of city, since the effectiveness of a device may differ considerably depending on local laws and attitudes. Cities also had to be found which were willing to install and maintain the devices until the after data could be collected.

The cities selected for testing of experimental devices included: Detroit, Michigan; Ann Arbor, Michigan; Saginaw, Michigan; Washington, D.C.; and Milwaukee, Wisconsin. A summary of the sites and cities used for testing each device is given in Table 36.

## Data Collection Procedures

A data collection scheme was developed to allow for the collection of traffic and pedestrian volumes, pedestrian-vehicle conflicts, pedestrian violations, and site characteristics. Two different data collection plans were considered for collection of operational and volume data, which included manual data collection and video recording techniques. Video recording was considered desirable to allow for close quality control of all data, since repeated passes could be made over the film to allow for checking and verification and guarantee data accuracy. The manual data collection was considered to be adequate in the later stages of the project after close control of data collection quality had been insured.

Most of the data were collected using a two video camera set-up, which allowed one camera to film the crosswalk of concern and the other camera to simultaneously film the pedestrian signal message. Using a signal mixer, the real-time image of the pedestrian signal message was superimposed into one corner of the video screen, so the pedestrian movements and conflicts could be easily recorded as a function of the pedestrian signal indication. This allowed the analyst, for example, to record the number of pedestrians crossing on the flashing DONT WALK interval, steady DONT WALK interval, and WALK interval. Counts were also made of pedestrians anticipating the WALK interval, or those waiting at the signal and stepping off the curb prior to the WALK signal. A time image generator was also used to superimpose the elapsed time directly onto the screen for use in recording data in 10-minute or other intervals.

To film the intersection, one camera was mounted from an elevated vantage point, usually from the second story window of a building or parking garage. The camera was adjusted to display the crosswalk of concern with an adequate view of the area near the crosswalk. The second camera was situated with an extension cable at a different vantage point to view the pedestrian signal facing the crosswalk of concern.

Table 36. Summary of cities and sites used in testing each device.

<u>Clearance Alternatives</u>

1. Pedestrian Signal Explanation Signs (Word or Symbolic)

   Saginaw, Michigan - Court St. and Michigan Ave. (Symbolic)
   Saginaw, Michigan - Court St. and Hamilton St. (Symbolic)
   Washington, D.C. - 18th St. and L St. (Word)
   Washington, D.C. - 17th St. and L St. (Word)

2. DONT START Signal Indication

   Ann Arbor, Michigan - S. State St. and Washington St.
   Washington, D.C. - 20th St. and L St., N.W.
   Milwaukee, Wisconsin - Broadway and Mason St.
   Milwaukee, Wisconsin - Mason St. and Jackson St.

3. Steady versus Flashing DONT WALK

   Washington, D.C. - 30th St. and M St.
   Washington, D.C. - 7th St. and D St.

<u>Alternatives for Turning Vehicles</u>

1. YIELD TO PEDESTRIANS WHEN TURNING Sign

   Detroit, Michigan - Cass Ave. and Lafayette St.
   Detroit, Michigan - Woodward Ave. and Grand Blvd.
   Milwaukee, Wisconsin - 27th St. and Wisconsin Ave.
   Milwaukee, Wisconsin - Michigan Ave. and Broadway

2. Pedestrian Signal Explanation Sign (Word or Symbolic)

   Saginaw, Michigan - Court St. and Michigan Ave. (Symbolic)
   Saginaw, Michigan - Court St. and Hamilton St. (Symbolic)
   Washington, D.C. - 18th St. and L St., N.W. (Word)
   Washington, D.C. - 14th St. and L St., N.W. (Word)

3. PEDESTRIANS WATCH FOR TURNING VEHICLES Sign

   Detroit, Michigan - Griswald St. and Larned St.
   Detroit, Michigan - Cass Ave. and Warren Ave.
   Milwaukee, Wisconsin - 11th St. and Mitchell St.
   Milwaukee, Wisconsin - 13th St. and Lincoln Ave.

4. WALK WITH CARE Signal Indication

   Ann Arbor, Michigan - Main St. and Washington St.
   Washington, D.C. - M St. and Wisconsin St.
   Milwaukee, Wisconsin - Mason St. and Milwaukee Ave.
   Milwaukee, Wisconsin - 16th St. & Wisconsin Ave.

5. Steady versus Flashing WALK

   Washington, D.C. - 30th St. and M St. (add Flashing WALK)
   Washington, D.C. - 7th St. and D St. (add Flasing WALK)
   Milwaukee - Mason St. and Jefferson St. (add Flashing WALK)
   Milwaukee - 27th St. and Wells St. (add Flashing WALK)

To collect data, trained technicians viewed the film and recorded the volume, violation, and conflict data on the coding form. The film had to be viewed twice, where basic pedestrian and traffic volumes were recorded on the first pass, and the conflicts and pedestrian violations were recorded on the second pass.

To optimize reliability in data collection, all data collectors were carefully trained, and numerous tests were conducted for consistency and reliability using film test sections. Ultimately, four different observers were used to conduct the counts of pedestrian and traffic volume. However, the same technician was used to record all conflict and violation data to prevent inter-rater variability which occurs whenever two or more people record conflicts and behavior data. Numerous checks were made throughout the data collection period to insure consistent and reliable results.

For the later phase of data collection (i.e., "after" data in Milwaukee) manual data collection was conducted using the same observers that had viewed the film data. All events were recorded in a similar manner as with the film, except that observers collected data at the site and no film viewing or related data extraction was necessary. Traffic counters (push button type) were used during both the video and manual data collection to count conflicts, violations, and volumes, and the values were recorded on data sheets at the end of each 10-minute data collection period. A brief procedural guide for data collectors was developed and used for training purposes, as shown in Appendix M.

For each location, all physical roadway information was collected by field observers, as discussed earlier. In many cases, the traffic signal timing varied over the data collection period, and this was recorded. All information collected at each site was coded onto appropriate coding forms and keyed into the computer. A computer listing of the keyed data was checked against the raw data sheets to insure accuracy. The corrected data were then used in the analysis to determine the effect of each experimental device.

## Data Analysis

Before and after data were collected for each experimental sign and signal device, and a comprehensive statistical analysis was conducted to determine the effect of each device on pedestrian behavior and related conflicts. The analysis consisted of conducting a series of Z-tests of proportions for comparing several measures of effectiveness (MOE's), such as the percentage of pedestrian violations and conflicts. For example, the percentage of pedestrian conflicts and violations in the before or "base" condition was computed. These percentages were matched with the corresponding after or "experimental" periods using the Z-test, and one of the following results were found (with the corresponding symbols):

- A - Significant difference was found in favor of the after (experimental) condition.

- B - Significant difference was found in favor of the before (base) condition.

- NC - No significant difference was found between the before and after periods.

- NA - The MOE was not applicable. For example, on a one-way street approach, conflicts involving right and left turning vehicles vehicles from other approaches are not applicable. Also, some MOE's are not applicable for certain types of experimental devices.

The symbol "*" was used to designate that the difference is significant at the 0.05 level, while the symbol "**" was used to designate that an the difference is significant at the 0.01 level.

Detailed summaries are provided in Appendix N regarding the Z-values, proportions and sample sizes of MOE's for each experiment. A summary of the findings is presented in the following sections.

When comparing the proportion of pedestrian conflicts and violations between the before and after periods, large changes in volumes of through and turning vehicles could obviously affect the results. To account for this possibility, several techniques were considered. In their study of various pedestrian sign and signal alternatives, Robertson [6] employed Sandler's A statistic to compare distributions of traffic volumes for comparable time intervals during the before and after periods. In most cases, traffic volumes were not significantly different. However, in cases where volumes differed significantly, there was no way of determining whether any change in conflicts was due to the experimental device, or due to the shift in traffic volume.

In order to account for possible changes in traffic volume between the before and after periods, a different approach was taken. First, the Z-values were determined for each MOE for each site. Then, data at each site were stratified into low, medium, and high levels of through traffic volume. A separate analysis was then conducted within each of the three volume levels. Then, data at each site was stratified again based on turning volumes for low, medium, and high levels and then analyzed for each of these groups. The results of the Z-tests within each traffic volume group were then compared to the results of the total data at each site to insure consistent results. Where the results in the individual traffic volume categories did not support the overall analysis, then differences in traffic volume were assumed to be partly responsible for the changes in the MOE. Detailed summaries of these Z-tests for each traffic volume category are summarized in Appendix O.

Each of the appropriate MOE's was used in evaluating the devices, however, due to the small sample sizes of some of the MOE's (i.e., pedestrian hesitation) some comparisons were not possible. For example, the Z-test requires a minimum of 30 events (i.e., conflicts or violations) in each of the before and after periods. Thus, if 500 pedestrians were observed in each of the before and after periods and aborted crossings dropped from 52 to 29, the sample size would be insufficient, since 29 events in the after period is less than the minimum of 30 at that one site. To address this issue, MOE's were analyzed individually and also grouped together into the following categories:

- Total conflicts with through vehicles
    - Pedestrian hesitation
    - Aborted crossing
    - Moving vehicle conflict
    - Run on clearance
    - Run vehicle conflict
- Total turning conflicts
    - Right-turn conflict
    - Left-turn conflict
    - Run-turning vehicle
- Total conflicts (conflicts with through plus turning vehicles)
- Total pedestrian violations
    - Leave curb on clearance interval
    - Leave curb on prohibitive (DONT WALK) interval
    - Anticipate WALK (leave curb just prior to WALK interval)

These four combined groups of conflicts and violations provide a better perspective on the overall effect of a sign or signal device. When conducting the Z-tests for each traffic volume category, the data base at each site was also divided into subsets, and thus, it was possible to analyze the combined groupings of MOE's for different sample sizes.

The following is a discussion of the results of the analysis relative to: (1) the pedestrian clearance alternatives; and (2) alternatives for turning vehicles.

## Pedestrian Clearance Alternatives

The three pedestrian clearance alternatives which were field tested in this study included the following:

- A pedestrian signal explanation sign which defines the meaning of the pedestrian signal indications.

- A three-section signal with the steady DONT START message during the clearance interval.

- The steady DONT WALK used during the clearance (and prohibitive crossing period) instead of the flashing DONT WALK.

These clearance alternatives are intended to improve pedestrian understanding, thus reducing violations and various resulting conflict types. Thus, all types of MOE's listed above were analyzed before and after the installation of each clearance device. The flashing DONT WALK was used as the before or base condition, unless otherwise stated. The results of the three alternatives are discussed below.

Pedestrian Signal Explanation Sign

The results of the tests using the pedestrian signal explanation sign are summarized in Table 37. At the two sites in Saginaw, Michigan, the symbolic signs were used, corresponding to the symbolic pedestrian signals at those sites. At site 2 in Saginaw, total clearance related conflicts decreased significantly (0.01 level). Anticipate WALK (i.e., leaving the curb early) decreased significantly at the two sites combined (0.05 level). However, no significant changes occurred in total conflicts, pedestrian violations, or any other type of pedestrian behavior at either of the sites. This can be partly explained by the fact that there was not much of a violation problem at the site prior to testing the signs, since only 16.2 percent of pedestrians crossed illegally in the before period compared to 15.3 percent in the after period.

At the two sites in Washington, D.C., the 4-section word signs were used which explained the flashing WALK as used in that city. Several significant changes occurred after installing the signs. For the two sites combined, a significant improvement resulted in overall pedestrian violations (0.01 level) from 44.4 percent (sample of 8,838 pedestrians) in the before period to 34.7 percent (sample of 7,971 pedestrians) in the after period. The total turning-related conflicts dropped from 687 (7.8 percent) to 535 (6.7 percent), which was significant at the 0.01 level based on a Z-value of 2.65. However, moving vehicle conflicts increased significantly (0.01 level) from 101 (1.1 percent) to 138 (1.7 percent), and no significant change was found in overall conflicts. Turn-related conflicts were not applicable MOE's at the sites, due to turn prohibitions from one-way street approaches. Several other significant changes in MOE's also resulted at the individual sites, as shown in Table 37.

Detailed Z-tests were conducted for various sub-groups of data for low, medium, and high levels of through and turning traffic. The results were in general agreement with the overall analysis, which suggests that

Table 37. Summary of results for the pedestrian signal explanation sign.

Experiment: Install signs to explain the meaning of the pedestrian signal indications.

| | City | Saginaw | | | Washington, DC | | |
|---|---|---|---|---|---|---|---|
| | Site Number | 1 | 2 | 1&2 | 3 | 4 | 3&4 |
| CONFLICTS | Pedestrian Hesitation | - | - | - | A* | B* | NC |
| | Aborted Crossing | - | - | - | - | - | - |
| | Moving Vehicle | - | - | - | NC | B** | B** |
| | Right-turn Vehicle | NC | NC | NC | A** | NA | NA |
| | Left-turn Vehicle | NC | NC | NC | NA | A** | NA |
| | Run Vehicle | - | - | - | - | B** | NC |
| | Run On Clearance | - | - | - | A* | NC | NC |
| | Run-turning Vehicle | - | - | - | - | - | - |
| | Total Clearance Related | NC | A** | A** | A** | B** | NC |
| | Total Turning Related | NC | NC | NC | A** | A** | A** |
| | Total Conflicts | NC | NC | NC | A** | NC | NC |
| VIOLATIONS | Leave Curb on Clearance | NC | NC | NC | A** | B** | B** |
| | Leave Curb on DONT WALK | - | - | NC | A* | A** | A** |
| | Anticipate Walk | - | - | A* | A** | B** | A** |
| | Total Violations | NC | NC | NC | A** | A** | A** |

Legend:
A = Significant difference in favor of after (experimental) condition.
B = Significant difference in favor of before (base) condition.
NC = No significant difference between before and after conditions.
* = Significant at the 0.05 level.
** = Significant at the 0.01 level.
- = Insufficient sample size.
NA = Not Applicable.

changes in traffic volumes did not affect the results discussed above. Summaries of the Z-test results for each traffic volume group are given in Appendix O.

In summary, the pedestrian signal explanation signs did not result in significant reductions in violations or conflicts at the two sites in Saginaw, Michigan, but resulted in a significant improvement in violations and some conflict types at the two sites in Washington, D.C. The reason for its increased effectiveness at the Washington, D.C. sites compared to the Saginaw sites is not fully known, although the violation rate was much higher in the before period at the Washington sites (44.4 percent) than at the Saginaw sites (16.2 percent), so there was more room for improvement. It should be recognized that these are small informational signs which must be read and understood by a large segment of the pedestrian population to be effective.

## DONT START Signal Indication

This device displays a steady DONT START indication during the clearance interval, a WALK (steady or flashing, depending on local use) during the permissive interval, and a steady DONT WALK during the prohibited crossing period. This device differs from an earlier DONT START signal tested by Robertson, where a 2-section signal was tested involving the use of the steady DONT START for both the clearance interval and the prohibited period.

Table 38 summarizes the results of the field stuidies at four sites where the three-section DONT START indication was tested. At the site in Ann Arbor, Michigan, no significant changes were observed in clearance-related conflicts, in turning conflicts, or in total conflicts. However, pedestrian hesitations increased and moving vehicle conflicts decreased significantly (0.05 level). Also, the percentage of violations increased significantly (0.05 level) during the after period at the Ann Arbor site. However, the DONT WALK period was increased by 4 seconds by the city personnel during the after period compared to the before period, and it is likely that this change was partly responsible for this increased violation rate. Also, on reviewing Z-tests for various traffic volume groups, no significant change in pedestrian violations were found for any group (Table 39). This implies that the increase in violations in the after period was likely due to shifts in traffic volume factors rather than the DONT START signal.

Table 38. Summary of results for the DONT START signal indication.

Experiment: Use steady DONT START pedestrian signal indication during the clearance interval.

| | City | Ann Arbor | Wash.,DC | Milwaukee | | |
|---|---|---|---|---|---|---|
| | Site Number | 5 | 6 | 7 | 8 | 7&8 |
| CONFLICTS | Pedestrian Hesitation | B* | B** | - | - | A** |
| | Aborted Crossing | - | - | - | - | - |
| | Moving Vehicle | A* | - | - | - | - |
| | Right-turn Vehicle | NC | A** | B* | NA | NA |
| | Left-turn Vehicle | NC | NA | NC | NA | NA |
| | Run Vehicle | - | - | - | - | - |
| | Run On Clearance | - | NC | - | - | - |
| | Run-turning Vehicle | - | - | - | NA | NA |
| | Total Clearance Related | NC | B** | A** | A** | A** |
| | Total Turning Related | NC | A** | NC | NA | NA |
| | Total Conflicts | NC | A** | A** | A** | A** |
| VIOLATIONS | Leave Curb on Clearance | A* | A** | A** | A** | A** |
| | Leave Curb on DONT WALK | B** | B** | A** | A** | A** |
| | Anticipate Walk | A** | A** | A** | NC | A** |
| | Total Violations | B* | A** | A** | A** | A** |

Legend:
A = Significant difference in favor of after (experimental) condition.
B = Significant difference in favor of before (base) condition.
NC = No significant difference between before and after conditions.
* = Significant at the 0.05 level.
** = Significant at the 0.01 level.
- = Insufficient sample size.
NA = Not Applicable.

Table 39. Summary of Z-test results by traffic volume group for DONT START signal indication.

EXPERIMENT: DONT START Signal Indication

SITE: Ann Arbor, Michigan - S. State St. and Washington St. (5)

| | Thru Volume Group | | | Turn Volume Group | | | All Volume Groups |
|---|---|---|---|---|---|---|---|
| | Low | Medium | High | Low | Medium | High | |
| Total Violations | NC | NC | NC | NC | NC | NC | B* |
| Thru Conflicts | - | NC | NC | NC | - | NC | NC |
| Turn Conflicts | - | NC | NC | NC | A* | NC | NC |
| Total Conflicts | - | NC | NC | NC | NC | NC | NC |

Legend:
A = Significant difference in favor of "after" (experimental) condition
B = Significant difference in favor of "before" (base) condition
NC = No significant difference between "before" and "after" conditions
* = Significant at the 0.05 level
** = Significant at the 0.01 level
- = Insufficient sample size
NA = Not Applicable

The DONT START signal was tested at one site in Washington, D.C., as summarized in Table 38. Overall conflicts dropped from 19.3 percent (640 of 3,310) in the before period to 13.0 percent (345 of 2,646) in the after period, which is a significant reduction at the 0.01 level. Total violations dropped from 22.8 percent to 18.7 percent, which is also a significant reduction (0.01 level). The reductions occurred in spite of increases in a few individual MOE's. For example, pedestrian hesitations increased from 0.9 percent to 2.8 percent (which may have been due to the novelty effect on a few pedestrians associated with the new signal) and was responsible for a significant increase in through conflicts from 3.3 to 5.1 percent, an increase of 1.8 percent. A review of Z-test results by volume group indicates significant reductions in total violations, total conflicts, and turn conflicts in virtually all volume groups (0.01 level).

At the two sites in Milwaukee, Wisconsin, where the DONT START signal indication was tested, significant reductions were found in total violations, total conflicts, and clearance-related conflicts (0.01 level in all cases). In fact, total conflicts dropped from 20.9 percent (391 of 1,870 pedestrians) in the before period to 13.8 percent (331 of 2,392) in the after period. Overall pedestrian violations dropped from 41.6 percent to 22.8 percent, and clearance-related conflicts were reduced from 8.9 percent to 3.7 percent. The Z-tests by volume groups agreed with the overall results from the Milwaukee sites.

In summary, the three section DONT START signal resulted in a significant reduction in conflicts and pedestrian violations compared to the standard flashing DONT WALK display at three of the four sites. The fourth site was in Ann Arbor, where no significant changes resulted. This may have been due to the different signal timing in the after period (4 seconds of additional DONT WALK) and the high percentage of college students (University of Michigan) who crossed. In fact, over 54 percent of pedestrians at this site violated the standard pedestrian signal in the before period, which was a higher violation rate than at any other site where testing was conducted. The three-section DONT START signal is intended to improve the pedestrians' understanding of the signal, but any type of pedestrian signal would likely have little or no effect on a pedestrian population which largely ignores pedestrian signals.

## Steady Versus Flashing DONT WALK Signal Indication

Of the cities selected for testing devices, none of them agreed to convert their signals to a steady DONT WALK display during the clearance interval for testing purposes (due to legal risks). However, in Washington, D.C., two sites were found where the pedestrian signal did not flash during the clearance interval or during the WALK interval. Thus, in the before period the signal displayed the steady WALK (permissive interval) and steady DONT WALK (clearance and prohibitive crossing period), and in the after period it displayed the flashing WALK during the crossing interval, the flashing DONT WALK during the clearance interval, and the steady DONT WALK during the prohibitive crossing interval.

A summary of the results of the steady versus flashing DONT WALK are shown in Table 40. No significant reductions resulted at the two sites in pedestrian violations, pedestrian hesitations, left-turn conflicts moving vehicle conflicts, or total conflicts. Left-turning-related conflicts dropped significantly, while total clearance conflicts increased significantly (0.01 level in each case).

It appears clear from the analysis at these sites that there is no significant difference in overall conflicts or violations due to using flashing signal indications or steady indications for the combined WALK and DONT WALK intervals. This finding basically agrees with the study by Robertson, which found that the steady DONT WALK had the same effectiveness as the flashing DONT WALK, and that the flashing WALK is not an effective means of warning pedestrians about turning vehicles. The testing in the Robertson study involved a comparison of the steady versus flashing WALK separately from the steady versus flashing DONT WALK. The results of this subsequent study are based on flashing both the WALK and the DONT WALK in the after period. In any case, the results basically agree with those by Robertson regarding no difference between steady and flashing signal indications.

Table 40. Summary of results for the steady versus flashing DONT WALK signal indication.

Experiment: Change the steady DONT WALK to a flashing DONT WALK during the clearance interval.

| | City | Washington, D.C. | | |
|---|---|---|---|---|
| | Site Number | 9 | 10 | 9&10 |
| CONFLICTS | Pedestrian Hesitation | NC | NC | NC |
| | Aborted Crossing | - | - | - |
| | Moving Vehicle | - | - | NC |
| | Right-turn Vehicle | A* | A** | A** |
| | Left-turn Vehicle | NC | NC | NC |
| | Run Vehicle | - | - | - |
| | Run On Clearance | - | - | - |
| | Run-turning Vehicle | - | - | - |
| | Total Clearance Related | NC | B** | B** |
| | Total Turning Related | A* | A** | A** |
| | Total Conflicts | A* | NC | NC |
| VIOLATIONS | Leave Curb on Clearance | NA | NA | NA |
| | Leave Curb on DONT WALK | NA | NA | NA |
| | Anticipate Walk | A** | A** | A** |
| | Total Violations | A** | NC | NC |

Legend:
A = Significant difference in favor of after (experimental) condition.
B = Significant difference in favor of before (base) condition.
NC = No significant difference between before and after conditions
* = Significant at the 0.05 level.
** = Significant at the 0.01 level.
- = Insufficient sample size.
NA = Not Applicable.

## Turning Vehicle Alternatives

The second category of alternatives which were field tested included sign and signal indications to warn pedestrians and/or motorists of possible turning conflicts. The devices tested included:

- Motorist regulatory YIELD TO PEDESTRIANS WHEN TURNING sign.
- The pedestrian signal explanation sign.
- Pedestrian warning PEDESTRIANS WATCH FOR TURNING VEHICLES sign.
- The WALK WITH CARE signal indication.
- The steady versus flashing WALK signal indication.

Each of these devices is termed as the experimental or after period. For the steady versus flashing WALK experiment in Washington, D.C., the steady WALK was used as the base or before period and the flashing WALK was used as the experimental condition, as indicated on the summary table. The results of the field testing are discussed below.

### YIELD TO PEDESTRIANS WHEN TURNING Sign

This sign was tested at two sites in Detroit, Michigan, and two sites in Milwaukee, Wisconsin. Since this sign was aimed at motorists approaching an intersection who turn left or right on the intersecting street, the MOE's selected for evaluation purposes include only those involving turning vehicles, as well as total conflicts. At the Detroit sites, signs were aimed at both left and right turning vehicles at site 11, but signs were aimed only at right turning vehicles at site 12 (since left-turns were prohibited). For the two sites combined, right-turn conflicts decreased from 20.1 percent (415 of 2,063 pedestrians) to 14.1 percent (414 of 2,926 pedestrians), which is significant at the 0.01 level. Left-turns were prohibited at one of the sites, so an analysis of left-turn conflicts is not applicable for both sites combined. For the two Detroit sites combined, total turning-related conflicts dropped significantly (21.6 to 15.7 percent), even though turn-related conflicts at one of the sites experienced no significant change. Total conflicts also dropped from 25.6 to 19.2 percent, which was significant at the 0.01 level (see Table 41).

At the two sites in Milwaukee, Wisconsin, a sign was installed for both left- and right-turning vehicles at both sites. Based on the analysis, a significant reduction was found in right-turn conflicts (8.8 to 5.8 percent), even though no significant change resulted at either individual site. However, no significant change resulted in left-turn conflicts. A significant reduction resulted in total turning conflicts at site 13 (0.05 level) and site 14 (0.01 level) and total conflicts dropped significantly (0.01 level) from 17.9 percent to 11.3 percent at the two sites combined.

Table 41. Summary of results for YIELD TO PEDESTRIANS WHEN TURNING sign.

Experiment: Install YIELD TO PEDESTRIAN WHEN TURNING sign.

| | City | Detroit | | | Milwaukee | | |
|---|---|---|---|---|---|---|---|
| | Site Number | 11 | 12 | 11&12 | 13 | 14 | 13&14 |
| CONFLICTS | Pedestrian Hesitation | - | - | - | - | - | - |
| | Aborted Crossing | - | - | - | - | - | - |
| | Moving Vehicle | NA | | | | | |
| | Right-turn Vehicle | A** | A** | A** | NC | NC | A** |
| | Left-turn Vehicle | - | NA | NA | - | - | NC |
| | Run Vehicle | NA | | | | | |
| | Run On Clearance | | | | | | |
| | Run-turning Vehicle | - | - | - | - | - | - |
| | Total Clearance Related | - | NC | NC | - | - | A** |
| | Total Turning Related | A** | NC | A** | A* | A** | A** |
| | Total Conflicts | A** | NC | A** | A* | A** | A** |
| VIOLATIONS | Leave Curb on Clearance | NA | | | | | |
| | Leave Curb on DONT WALK | | | | | | |
| | Anticipate Walk | | | | | | |
| | Total Violations | | | | | | |

Legend:
A = Significant difference in favor of after (experimental) condition.
B = Significant difference in favor of before (base) condition.
NC = No significant difference between before and after conditions.
* = Significant at the 0.05 level.
** = Significant at the 0.01 level.
\- = Insufficient sample size.
NA = Not Applicable.

An analysis of the data by individual volume groups revealed no conflicting results. The effectiveness of the sign was not influenced by the level of through or turning volume. Thus, the sign may be considered applicable to a wide range of traffic volumes.

In conclusion, the YIELD TO PEDESTRIANS WHEN TURNING sign was found to be effective in reducing turning conflicts, and in particular, right-turning conflicts. Left-turning conflicts were not significantly affected, possibly smaller sample sizes and other effects such as due to the pre-occupation of left-turning motorists with through traffic, other visual information and poor sign location. Also, pedestrians are inherently more aware of right-turning vehicles than of left-turning vehicles, as noted in the literature. The signs were equally effective for low, medium, and high traffic volume levels.

## Pedestrian Signal Explanation Sign

This device was tested at two sites in Washington, D.C. and Saginaw, Michigan, as discussed previously. The sites in Washington, D.C. had the word pedestrian signal indications which utilized the flashing WALK indication. The pedestrian signal indication signs for this test described the WALK indication was OK TO CROSS and the flashing WALK as START CROSSING - WATCH FOR TURNING CARS as shown in Figure 7. The sites in Saginaw were equipped with symbolic pedestrian signals, which utilized the steady walking man to indicate the crossing interval and did not utilize a flashing symbol to indicate potential turning-vehicle conflicts. The sign used for this test featured the walking man symbol with the word "Steady" and the caption OK TO CROSS - WATCH FOR TURNING CARS.

The results of this test are shown in Table 37. As discussed earlier, there was no significant difference in turn-related conflicts at the site in Saginaw, Michigan, but there was a significant reduction in turnrelated conflicts at the two Washington, D.C. sites.

## PEDESTRIANS WATCH FOR TURNING VEHICLES Signs

This sign is intended to reduce turning vehicle-pedestrian conflicts by alerting pedestrians to the possibility of turning vehicles. Thus, the MOE's used in analyzing this device were turning conflicts and total conflicts, as shown in Table 42. Right-turning conflicts at the two Detroit, Michigan, sites dropped significantly (0.01 level) from 17.5 percent to 8.1 percent. Left-turn conflicts were not applicable at one site (left turns were prohibited) and did not change significantly at the other Detroit, Michigan, site. Significant reductions resulted in total turning conflicts (18.8 percent to 8.4 percent) and in total conflicts (23.9 percent to 12.9 percent), which are both significant at the 0.01 level.

At the two sites in Milwaukee, Wisconsin, a significant reduction was found in right-turn vehicle conflicts (5.8 to 3.4 percent), although an

Table 42. Summary of results for PEDESTRIANS WATCH FOR TURNING VEHICLES sign.

Experiment: Install PEDESTRIANS WATCH FOR TURNING VEHICLES sign.

| | City | Detroit | | | Milwaukee | | |
|---|---|---|---|---|---|---|---|
| | Site Number | 15 | 16 | 15&16 | 17 | 18 | 17&18 |
| CONFLICTS | Pedestrian Hesitation | - | - | NC | - | - | - |
| | Aborted Crossing | - | - | - | - | - | - |
| | Moving Vehicle | NA | | | | | |
| | Right-turn Vehicle | A** | A** | A** | - | NC | A** |
| | Left-turn Vehicle | NA | - | NA | - | - | - |
| | Run Vehicle | NA | | | | | |
| | Run On Clearance | | | | | | |
| | Run-turning Vehicle | - | - | - | - | - | - |
| | Total Clearance Related | - | B** | NC | A** | - | A** |
| | Total Turning Related | A** | A** | A** | - | NC | A** |
| | Total Conflicts | A** | NC | A** | A** | NC | A** |
| VIOLATIONS | Leave Curb on Clearance | NA | | | | | |
| | Leave Curb on DONT WALK | | | | | | |
| | Anticipate Walk | | | | | | |
| | Total Violations | | | | | | |

Legend:
A = Significant difference in favor of after (experimental) condition.
B = Significant difference in favor of before (base) condition.
NC = No significant difference between before and after conditions.
* = Significant at the 0.05 level.
** = Significant at the 0.01 level.
\- = Insufficient sample size.
NA = Not Applicable.

inadequate sample of left-turn conflicts resulted in that type of conflict not being evaluated. Total turning conflicts dropped significantly (0.01 level) as a result, and total conflicts dropped from 12.0 to 6.7 percent. The results from the Z-tests for various traffic volume groups revealed consistent results.

In summary, the sign PEDESTRIANS WATCH FOR TURNING VEHICLES was found to be effective at each of the four test sites, particularly relative to right-turn vehicle conflicts. The signs, however, have no proven effect relative to left-turn-related conflicts.

WALK WITH CARE Signal Indication

The WALK WITH CARE display was tested as a replacement to the steady or flashing WALK display at four sites, as summarized in Table 43. Since the WALK WITH CARE message provides a general warning indication to pedestrians, all of the selected MOE's were expected to be related in some way to this device, although the indication was expected to have the greatest impact on conflicts related to turning vehicles.

At the site in Ann Arbor, Michigan, right-turn conflicts dropped from 8.1 percent (46 of 571 pedestrians) to 3.9 percent (95 of 2,427 pedestrians), which is significant at the 0.01 level. Note that a larger sample size of pedestrians was collected in the after period, since several days of after data were collected over a 3-month period to determine long-term effects of the device. Significant reductions (0.01 level) were also found in total clearance-related conflicts (7 percent to 2.1 percent), and total conflicts (17.7 to 7.8 percent). Also, total pedestrian violations were reduced from 45.9 percent to 17.7 percent, which is also significant at the 0.01 level.

At the site in Washington, D.C., significant reductions (0.01 level) resulted in right-turn conflicts (18.7 to 15.4 percent), left-turn conflicts (2.8 to 1.7 percent), total turning-related conflicts (23.0 to 18.2 percent), and total conflicts (28.2 to 24.4 percent). Pedestrian hesitations increased from 1.9 percent to 3.0 percent, which was a significant increase at the 0.05 level. A significant reduction was also observed in pedestrian violations, where 23.5 percent of the 1,844 pedestrians were involved in violations during the before period, compared to 19.8 percent of the 3,269 pedestrians in the after period.

The two sites in Milwaukee, Wisconsin, with the WALK WITH CARE signal indication also experienced significant reductions in conflicts and violations. For the two sites combined, significant reductions resulted in pedestrian hesitations (2.6 to 1.6 percent), right-turn conflicts (8.3 to 5.8 percent), left-turn conflicts (4.7 to 2.2 percent), and total clearance-related conflicts (7.0 to 3.3 percent). Total conflicts also dropped significantly (0.01 level) from 20.6 percent to 11.6 percent, and pedestrian violations dropped by nearly two-thirds from 35.9 percent (of

Table 43. Summary of results for the WALK WITH CARE signal.

Experiment: Use of the WALK WITH CARE signal indication during the crossing interval.

| | City | Ann Arbor | Washington | Milwaukee | | |
|---|---|---|---|---|---|---|
| | Site Number | 19 | 20 | 21 | 22 | 21&22 |
| CONFLICTS | Pedestrian Hesitation | - | B* | - | - | A* |
| | Aborted Crossing | - | - | - | - | - |
| | Moving Vehicle | - | - | - | - | - |
| | Right-turn Vehicle | A** | A** | A** | A* | A** |
| | Left-turn Vehicle | - | A** | - | - | A** |
| | Run Vehicle | - | - | - | - | - |
| | Run On Clearance | - | - | - | - | - |
| | Run-turning Vehicle | - | - | - | - | - |
| | Total Clearance Related | A** | NC | A** | - | A** |
| | Total Turning Related | A** | A** | A** | A** | A** |
| | Total Conflicts | A** | A** | A** | A** | A** |
| VIOLATIONS | Leave Curb on Clearance | NC | NC | NC | A** | A** |
| | Leave Curb on DONT WALK | A** | NC | A** | A** | A** |
| | Anticipate Walk | - | A** | - | - | - |
| | Total Violations | A** | A** | A** | A** | A** |

Legend:
A = Significant difference in favor of after (experimental) condition.
B = Significant difference in favor of before (base) condition.
NC = No significant difference between before and after conditions.
* = Significant at the 0.05 level.
** = Significant at the 0.01 level.
\- = Insufficient sample size.
NA = Not Applicable.

3,127 pedestrians) to 12.7 percent (of 1,866 pedestrians) which is significant at the 0.01 level (and a Z value of 17.8). Of the Z-tests conducted for each traffic volume category, results were basically similar to those discussed above for the total data base. The significant reductions in conflicts and violations were more prevalent for medium and high levels of turning volume than for low volume periods.

In addition to the formal field evaluation of the WALK WITH CARE signal indication, the new signal was apparently responsible for preventing at least one known pedestrian from being struck by a car on March 29, 1983, in Ann Arbor, Michigan. A letter was received from a private citizen in that city, sent to the city department of transportation explaining the events leading up to a near-accident situation. The citizen (pedestrian) credited the WALK WITH CARE signal for causing him to stop running into the street and to look around and barely avoid a vehicle running the red light. A copy of the letter (name withheld) is given in Appendix P.

The results of field testing at four sites in three cities indicates that the WALK WITH CARE signal indication is effective in reducing turn-related conflicts as well as pedestrian violations. It must be remembered that the four sites selected had a problem with turning vehicles conflicting with pedestrian traffic prior to the field tests. It can be assumed that the WALK WITH CARE signal can be effective at sites with a problem with conflicts or accidents involving turning vehicles conflicting with pedestrians. However, similar results may not necessarily occur at sites with low levels of turning vehicles and/or low pedestrian volumes.

## Steady Versus Flashing WALK

The steady WALK display was compared to the flashing WALK display at four total sites. At two sites in Washington, D.C., the steady WALK (permissive phase) was originally used in conjunction with a steady DONT WALK (clearance and prohibitive interval). After conversion to flashing WALK and flashing DONT WALK (clearance interval only), the analysis showed no significant difference in violations or total conflicts, as discussed earlier.

The isolated effect of the flashing versus steady WALK was tested at two sites in Milwaukee, Wisconsin, as shown in Table 44. No significant change resulted in pedestrian violations at the two sites combined, although a significant reduction appeared in total conflicts, turning conflicts, and clearance conflicts. However, upon checking the results of the Z-tests by volume groups, these findings are not fully supported. For example, within the individual volume groups, total conflicts were reduced significantly only for one volume group at one of the two sites. A large increase in hourly pedestrian volume (134 to 290) combined with shifts in right- and left-turning volume and lower through volume in the after period could also be partly responsible for the results.

Table 44. Summary of results for the steady versus flashing WALK signal indication.

Experiment: Change the steady WALK to a flashing WALK.

| | City | Washington, D.C. | | | Milwaukee | | |
|---|---|---|---|---|---|---|---|
| | Site Number | 9 | 10 | 9&10 | 23 | 24 | 23&24 |
| CONFLICTS | Pedestrian Hesitation | NC | NC | NC | - | - | - |
| | Aborted Crossing | - | - | - | - | - | - |
| | Moving Vehicle | - | - | NC | - | - | - |
| | Right-turn Vehicle | A* | A** | A** | - | NA | NA |
| | Left-turn Vehicle | NC | NC | NC | - | NC | A** |
| | Run Vehicle | - | - | - | - | - | - |
| | Run On Clearance | - | - | - | - | - | - |
| | Run-turning Vehicle | - | - | - | - | - | - |
| | Total Clearance Related | NC | B** | B** | A** | - | A** |
| | Total Turning Related | A* | A** | A** | NC | A* | A** |
| | Total Conflicts | A* | NC | NC | A** | A* | A** |
| VIOLATIONS | Leave Curb on Clearance | NA | NA | NA | - | - | B** |
| | Leave Curb on DONT WALK | NA | NA | B* | A** | - | NC |
| | Anticipate Walk | A** | A** | A** | NC | - | NC |
| | Total Violations | A** | NC | NC | NC | NC | NC |

Legend:
- A = Significant difference in favor of after (experimental) condition.
- B = Significant difference in favor of before condition.
- NC = No significant difference between before and after conditions.
- * = Significant at the 0.05 level.
- ** = Significant at the 0.01 level.
- \- = Insufficient sample size.
- NA = Not Applicable.

In summary, the results of the analysis of the sites in Milwaukee and the sites in Washington, D.C., provide evidence that little or no difference exists relative to the flashing or steady WALK display in terms of pedestrian conflicts.

## Conclusions and Recommendations

The following conclusions and recommendations were developed based on the results of the analysis. The first three conclusions involve clearance alternatives and the next four relate to alternatives to indicate potential conflicts with turning vehicles.

1. The pedestrian signal explanation signs were found to have no effect at two sites and were effective at two other sites in reducing pedestrian violations and turning conflicts. The use of these signs is recommended in conjunction with other public education and/or enforcement programs.

2. The steady DONT START clearance indication was found to result in a significant improvement over the flashing DONT WALK display in terms of pedestrian violations and associated clearance-related conflicts. In a 1974 study, Robertson [6] found that the DONT START message offered little or no improvement over the DONT WALK message. However, the steady DONT START display tested in that study was used for both the clearance interval and prohibitive interval, and no distinction was given to pedestrians for the clearance interval. The three-phase pedestrian signal tested in this study displays a WALK (permissive interval) steady DONT START (clearance interval) and a steady DONT WALK (prohibitive crossing interval). The three-phase pedestrian signal displays the DONT START which is comparable to the amber phase of a traffic signal for motorists.

3. The use of the steady DONT WALK display for the clearance interval provides no improvement over the flashing DONT WALK.

4. The YIELD TO PEDESTRIANS WHEN TURNING sign was found to be effective in reducing right-turn conflicts, although no significant changes resulted in left-turn conflicts. The sign would be most appropriate for use on the right side of intersection approaches, particularly in cases where right-turning motorists commonly fail to yield the right of way to pedestrians.

5. The PEDESTRIANS WATCH FOR TURNING VEHICLES sign was also found to be effective in reducing right-turn conflicts. This sign would be appropriate for use in place of or in conjunction with the YIELD TO PEDESTRIANS WHEN TURNING sign discussed above. The PEDESTRIANS WATCH FOR TURNING VEHICLES sign could also be applicable to sites

with a high incidence or potential for right-turn pedestrian accidents.

6. The WALK WITH CARE signal display was tested in conjunction with the WALK interval to warn pedestrians of turning vehicles. The results of the field tests at four sites in three cities indicates that the WALK WITH CARE display is effective in reducing turn-related conflicts as well as pedestrian violations. Further analysis showed that these displays were effective for moderate to high right-turn volumes. It is recommended that the WALK WITH CARE display should be used only at those intersections with: (1) a high incidence of pedestrian accidents involving right- or left-turning vehicles; (2) moderate to high turning volumes and numerous turning pedestrian conflicts; or (3) a high incidence of pedestrian violations. The overuse of this display would likely reduce its effectiveness, although it could be a highly effective safety treatment for locations with an abnormally high incidence of pedestrian accidents.

7. The flashing WALK signal has no proven benefit over the steady WALK display in terms of warning pedestrians of turning vehicles. Based on studies by Robertson and others, the distinction between the flashing and steady WALK is understood by less than 3 percent of pedestrians [6]. The flashing WALK display is not recommended for use.

Based on the findings of this study, several recommendations are relevant regarding the inclusion of these devices in the Manual on Uniform Traffic Control Devices (MUTCD), as follows:

1. The option for a flashing WALK display should be taken out of the MUTCD, since it offers no advantage to the steady WALK display and only serves to confuse pedestrians, according to other major studies.

2. The signs PEDESTRIANS WATCH FOR TURNING VEHICLES (warning sign) and YIELD TO PEDESTRIANS WHEN TURNING (regulatory sign) should be added to the MUTCD, as optional signs to be installed at sites where a particular problem exists with accidents or conflicts relative to right-turn vehicles interacting with pedestrians.

3. The pedestrian signal explanation sign (both word and symbolic options) should be added to the MUTCD to inform pedestrians of the meaning of existing signal indications.

4. The WALK WITH CARE signal display should be added to the MUTCD as a special device which can be used as an option at high pedestrian accident locations or at locations with an unusual problem of heavy vehicular turning movements and moderate to high pedestrian

volumes. Also, approaches with high approach speeds and/or poor sight distance between vehicles and pedestrians are locations that could likely benefit from the use of the WALK WITH CARE signal indication.

5. Further testing of the three-phase DONT START pedestrian signal is needed to determine whether it should be adopted on a national basis. The symbolic pedestrian signals are desirable from an international perspective, but problems may exist regarding pedestrians understanding the flashing versus the steady hand message. The three-section DONT START display may possibly be more understandable to pedestrians, even through it transmits a word message and not a symbolic one. The three sections operate similar to a three-section traffic signal and may be easily understood, especially since a yellow DONT START is used as the change interval.

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# CHAPTER IV - INVESTIGATION OF THE PEDESTRIAN YIELD CONCEPT

One of the major problems with pedestrian signals is the lack of compliance to the steady and flashing DONT WALK intervals. A study by Jennings et al. found that of a sample of 107 pedestrians crossing at intersections with pedestrian signals, about 26 percent crossed during the DONT WALK signal indication [1]. In a recent study by Robertson, the levels of compliance were determined for intersections in 9 cities throughout the U.S., (utilizing 1 to 6 intersections per city). The average pedestrian compliance rates ranged from 43 percent in Buffalo, New York to 89 percent in Tempe, Arizona [2]. In the analysis of 2,081 pedestrian accidents related to signalized intersections in 15 U.S. cities, Zegeer et al., found that only about 49 percent of the pedestrians involved in these accidents were crossing with the light [3]. Thus, pedestrian violations appear to be associated with pedestrian accidents.

The reasons for pedestrian crossing violations were examined in a study by Forsythe and Berger, in which 244 pedestrians were interviewed after making unsafe (illegal) crossings [4]. The primary reason given for illegal crossings was time-related with 69 percent (168) of the responses indicating "hurrying" or "convenience". Other reasons given included "light traffic" or "cars were stopped" (11 percent) and "did not see or notice" (10 percent). The lack of respect for the pedestrian signal was clearly evidenced from: (1) observed pedestrian violations; and (2) the responses of pedestrians who violated the DONT WALK signal message.

One of the possible reasons for the lack of respect for pedestrian signals is that pedestrians often see the DONT WALK message when they perceive that they can make a safe crossing. Thus, they often cross in violation of the DONT WALK message without any adverse results (i.e., they are not hit by a car and they are not given a citation for their illegal crossing). Over time, pedestrians may be conditioned to disregard pedestrian signals and may cross: (1) with the vehicular traffic signal without regard to the pedestrian signal; (2) when they perceive an acceptable gap in traffic; or (3) with little or no regard for the traffic control devices.

The use of a yield sign or signal for pedestrians has been proposed as a means of resolving the non-compliance problem. The concept is comparable to the right-turn-on-red situation, which allows motorists to turn right after stopping and yielding to oncoming traffic and to pedestrians. A yield sign or signal for pedestrians, as suggested by some, would permit pedestrians to cross against the traffic signal indication at certain locations or specific times of the day. Yield sign or signal devices have been suggested particularly for nighttime or off-peak periods when frequent gaps would exist in traffic. The concept is intended to improve pedestrian respect and compliance to the pedestrian signal, and reduce pedestrian delay by making the signals more responsive to existing highway and traffic conditions.

The purpose of this study was to investigate the use of yield signs or signals for pedestrians. Candidate yield sign and signal devices were developed and the yield concept was evaluated in terms of: (1) its ability to fulfill a need; (2) safety implications; (3) effect on pedestrian delay; (4) legality; and (5) feasibility. Recommendations are made regarding the yield signs and signal devices, and alternatives to the yield concept were reviewed and evaluated.

## Background and Overview

One of the first documented discussions of yield signs or signals for pedestrians was made in a proposal submitted to the National Joint Committee on Uniform Traffic Control Devices in November, 1977. The proposal suggested that since drivers are permitted to use their own judgement in certain situations (at yield signs, right-turn-on-red locations, etc.), consideration should be given to providing pedestrians with such rights through the use of a yield sign or signal. Further, the yield device was proposed to be used along with the WALK or DONT WALK signal indication, particularly at intersections with intermittent vehicle flows or where traffic volumes are low [5].

In June of 1978, the National Advisory Committee and the Federal Highway Administration denied the request for a change in the MUTCD, which would have allowed a fourth signal indication for pedestrians in the form of a "yield" condition. The primary reasons given for the denial were as follows [6]:

- No need for a pedestrian yield device had been identified from previous research.
- No specific yield device had been proposed for consideration.
- Any pedestrian yield device would require changing existing laws in many states.

In spite of the denial for the new pedestrian yield device, the Committee acknowledged the high rate of pedestrian violations of the DONT WALK signal indication, and suggested further research relative to the pedestrian yield concept [6].

Research relative to the pedestrian yield concept requires that a clear understanding of pedestrian behavior be established. This understanding will allow pedestrian problems and solutions to be viewed in proper perspective. The pedestrian violators of the DONT WALK signal can be classified as either: (1) those who do not understand the signal messages, (i.e., young pedestrians, non-English speaking, or others); (2) those who understand the pedestrian signal message but choose not to comply with it; or (3) those who do not notice or see the pedestrian signal through a visual impairment or through inattentiveness. Each of these subgroups requires a different solution. For example, pedestrians who do not understand the signals may be aided by the use of educational programs (i.e., school safety training, radio and television advertisements, signing and brochures), or by better and more self-explanatory pedestrian signal devices (i.e., symbolic messages).

The yield sign or signal concept is primarily aimed at those violators who understand the signal but do not comply with it. Various alternatives exist for dealing with this group. These include:

- Pedestrian yield signs or signals.
- Other types of traffic control measures which are intended to improve pedestrian compliance (i.e., pedestrian actuation devices, modified signal timing, etc.).
- Educational programs to convince pedestrians of the need to comply with pedestrian signals and other traffic control devices (possibly by warning them of their chances of being hit by a motor vehicle or given a citation).
- Improved police enforcement (with judicial support in upholding citations).
- Combinations of the above.

It must be emphasized that each of these four options listed above represents a possible way of addressing the same specific problem, that is, pedestrians who understand the DONT WALK pedestrian signal indication but knowingly violate it. This chapter summarizes the investigations conducted relative to the application of the yield concept as a means to enhance the effectiveness of pedestrian signal devices. The other alternatives are also discussed in an effort to establish the relative viability of the yield concept.

## Development of Yield Sign and Signal Devices

In order to properly evaluate the yield concept for pedestrians, one of the first questions addressed was: "What specific types of sign and/or signal device might be used to transmit the intended yield message to pedestrians?" A total of seven candidate yield sign and signal options were conceptualized, including the following:

- A three-section pedestrian signal head with the standard DONT WALK and WALK messages on the top two sections. The third signal lens would say YIELD TO VEHICLES and would only be activated during periods of low traffic volume (i.e., nighttime and off-peak periods), during which time the DONT WALK message would be turned off.

- A single illuminated pedestrian signal head which flashes YIELD or YIELD TO VEHICLES in orange at certain times or throughout the day or night.

- A pedestrian sign which says YIELD TO VEHICLES and opens up during low-volume periods. The sign could be located at intersections or midblock locations with standard pedestrian signals which are automatically turned-off when the sign opens up. The open/close sign concept has been used previously with regulatory speed limit signs in school zones which open up during school crossing periods.

- A variable message sign which is activated under certain times or traffic volume conditions. The message could be PEDESTRIANS - YIELD TO VEHICLES - CROSS WHEN CLEAR.

- An audible message which says PEDESTRIANS, PLEASE YIELD TO VEHICLES AND CROSS ONLY WHEN THE ROADWAY IS CLEAR. This could also be used in conjunction with some form of visual yield sign or signal message.

- A sign YIELD TO MOTORISTS displayed to pedestrians along with a pedestrian crossing symbol sign for approaching vehicles.

- A pedestrian yield signal that is activated from vehicle loop detectors placed in advance of the pedestrian crosswalk(s). During times when the vehicle signal is red, the pedestrian signal would display a DONT WALK upon being actuated by an approaching vehicle, and would display a yield message when not actuated by a vehicle.

Detailed descriptions of these alternatives are given in Appendix Q.

Before rank ordering or field testing of the pedestrian yield alternatives could be conducted, it was necessary to investigate the basic pedestrian yield concept based on the best available information as discussed below.

## Review of the Pedestrian Yield Concept

The basic pedestrian yield concept (i.e., allowing pedestrians to cross the street against a traffic signal when conditions permit) was evaluated based on the following criteria:

- Criterion 1 - Ability to fulfill a need
- Criterion 2 - Possible safety implications
- Criterion 3 - Effect on pedestrian delay
- Criterion 4 - Legality of the concept
- Criterion 5 - Feasibility of implementation

These criteria were established based on the intended objective of the yield concept and the possible effects which might result from its use. The following is a discussion of the yield concept in terms of these five criteria.

### Criterion 1 - Ability to Fulfill a Need

The ability of the yield sign/signal to fulfill a definite need was examined. The need in this case is to improve pedestrian safety by reducing the high percentage of pedestrians who violate pedestrian signals and cross when traffic is approaching. This need is a real one, based on high pedestrian violation rates in many cities and on the fact that about half of all pedestrian accidents at signalized intersections involve a pedestrian violation [2,3]. The pedestrian yield concept was believed by some to be a partial solution to this problem, if behavioral and legal questions can be resolved. Existing pedestrian behavior and the resulting level of signal violations has evolved over several decades and has been shaped by such things as:

- Cultural, attitudinal, and lifestyle differences of various geographic areas.

- Local laws and ordinances.

- Local enforcement policies and judicial decisions related to pedestrians compliance with traffic control devices.

- Emphasis on safety and compliance through the media (radio, newspapers, television) and safety training in the school systems and through civic organizations, etc.

- Types of traffic control devices, their clarity and appropriateness.

The pedestrian yield concept was believed to have a positive effect on pedestrian behavior by improving the appropriateness of devices to allow pedestrians to cross at some locations and times where such crossings would ordinarily be prohibited. (i.e., crossing against the traffic signal when an acceptable gap exists). In this manner, greater respect for the pedestrian devices might result, and the overall compliance rate would improve at locations or times when crossing is prohibited (i.e., DONT WALK signal is in effect). While this concept may initially sound appealing, some difficulties are likely to result. These would include:

- The addition of the yield devices may create confusion to pedestrians, since they would be faced with a new and different type of message than has been used in the past. It may also be difficult to develop a sign or signal message which could simply and clearly convey the message to the majority of pedestrians using the crossing.

- At locations with the yield device, pedestrians may reason that "If I can use my own judgment to cross at this site (or during certain hours), then it should be all right for me to use my judgment to cross at other sites (or times) when I have an adequate gap, even though crossing traffic may have the right of way". The result could possibly be a loss of respect by pedestrians for other or all pedestrian signals, thereby totally defeating the intended purpose of the device.

- As stated above, the types of traffic control devices (and their appropriateness) is just one of the many factors listed previously (i.e., laws and ordinances, lifestyles, and enforcement), which are thought to affect compliance to pedestrian signals. Pedestrians have been conditioned in the past to violate pedestrian signals and/or cross against the traffic in many cities. Allowing more of such actions with a yield sign or signal message will not solve the basic problem. Pedestrian safety is enhanced by increasing the separation between vehicles and pedestrians, either in time or distance. Allowing more pedestrians to cross between on-coming traffic will likely cause many pedestrians to take advantage of the situation and to begin crossing at will. Also, motorists may be caught off-guard by a greater number of pedestrians crossing the road during the vehicle phase.

In summary, even though there is a demonstrated need for improving pedestrian compliance, the pedestrian yield concept is not thought to be an effective solution, and it was rated as poor in terms of Criterion 1.

Criterion 2 - Possible Safety Implications

As discussed previously, there is a strong possibility that the use of a yield device could actually decrease pedestrian respect and compliance for pedestrian signals, since pedestrians would be allowed to cross "against the light". Also, where the yield device is used, pedestrians would be allowed to cross on the basis of their judgment of a safe gap in traffic. This could cause problems, particularly with respect to:

- Follow the leader attitudes, where pedestrians (particularly children) would observe a pedestrian crossing the street and follow the example.

- Young children or other pedestrians who have trouble judging an acceptable gap in traffic.

- Elderly or handicapped pedestrians with slower than average walking speeds who require a much longer than average acceptable gap.

- Young children, non-English speaking, uneducated, or others who would have problems understanding the meaning of the yield concept. There are still a large number of pedestrians (particularly school children, elderly, and foreign immigrants), who do not have a drivers license and who would not intuitively understand a pedestrian yield device.

- The yield concept would probably be used commonly at night when traffic volumes are low. Thus, the problem of darkness combined with additional pedestrian street crossings "against the light" could have a serious adverse impact on pedestrian accidents.

To illustrate the nighttime pedestrian accident problem, a study was conducted by Robertson [2] in which pedestrian accident risk was computed for each hour of the day. The risk was defined as the percent of pedestrian accidents divided by the percent of volume, as shown in Figure 14. Between 7:00 p.m. and 7:00 a.m., risk factors range between about 2 to more than 50, where a risk factor of 1.0 is the overall daily value. The high risk to pedestrians at night at the present time would likely increase further as a result of yield sign or signal devices, since it would encourage more pedestrians to cross against the light night.

Overall, the possible safety implications of the pedestrian yield concept is uncertain, but is likely to result in increased pedestrian accidents, particularly to the young, elderly, and handicapped. The nighttime pedestrian accident problem might also increase, due to the use of the yield message during off-peak and nighttime conditions. Thus, a rating of poor was also given to the pedestrian yield concept based on criterion 2.

Criterion 3 - Effect on Pedestrian Delay

The effect of the pedestrian yield concept on pedestrian delay can be discussed in terms of two distinct groups of pedestrians: (1) pedestrians who routinely obey pedestrian signal indications; and (2) pedestrians who routinely disobey pedestrian signal indications (for whatever reasons), and cross the street at their own discretion. For the second group of pedestrians (i.e., the violators), the pedestrian yield sign or signal

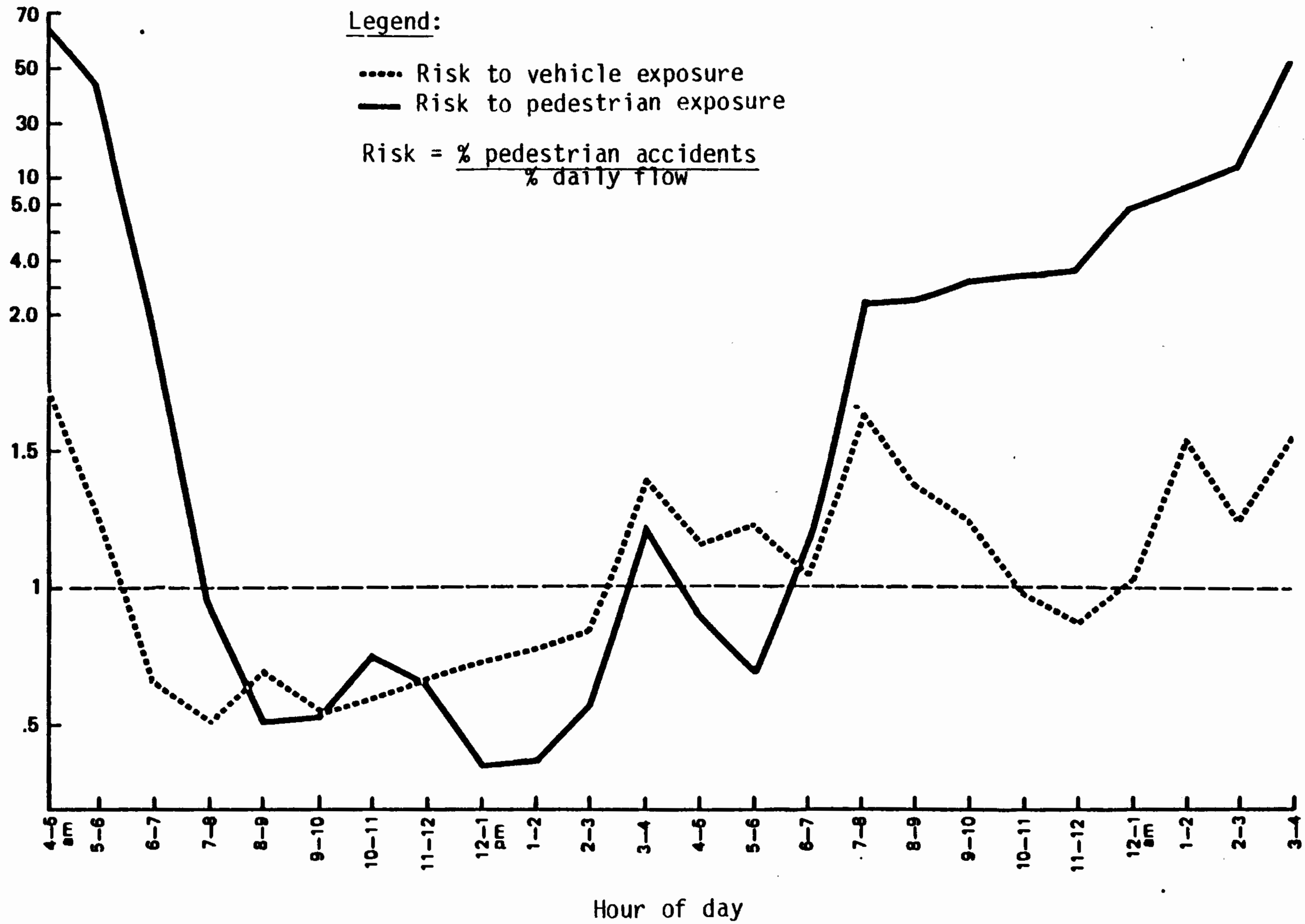


Figure 14. Accident risk by time of day based on exposure.

Source: Robertson [2]

messages should have little or no effect on their delay, since the yield message would essentially give them permission to cross the street as they have previously done without the yield device. For the pedestrians who typically obey pedestrian signals (group 1), the yield concept is expected to reduce their delay at times and locations where the yield device is used.

Pedestrian delay at a signalized intersection is a function of many factors, such as signal timing, pedestrian volume, traffic volume, street width, and pedestrian compliance. According to Robertson, "Pedestrians who are willing to trust their own judgment of gaps in traffic incur less delay than those who comply with the signal" [2]. This would indicate that the use of the pedestrian yield sign or signal concept would result in decreased pedestrian delay.

The amount of delay reduced by the pedestrian yield concept and the locational conditions for various levels of reduced pedestrian delay is the next issue. Goldschmidt found that the portion of pedestrians delayed was sensitive to changes in traffic volumes when vehicle volumes were less than 800 to 1,000 vehicles per hour. Pedestrian delay becomes most severe for traffic volumes above 1,000 vehicles per hour. Mean pedestrian delay at an intersection was found to be sensitive to changes in conditions at higher levels of traffic volumes. Mean pedestrian delay was less than 8 seconds at 1,000 vehicles per hour, and nearly 20 seconds for a traffic volume of 2,000 per hour [7].

The distribution of pedestrian volumes by time of day was another important issue in assessing delay implications of yield sign or signal indications. For example, based on 24-hour pedestrian volume counts for intersections in Seattle, Washington, 86 percent of daily pedestrian volumes occur between 7:00 a.m. and 7:00 p.m. (12 highest hourly volumes). Thus, a yield signal operating between 7:00 p.m. and 7:00 a.m. would be viewed by only about 14 percent of the daily pedestrian population as discussed in Chapter II.

The pedestrian yield sign or signal was originally proposed as a device to be used in conjunction with WALK/DONT WALK signals at signalized intersections [5]. For an intersection with a fixed-time signal and a 60-second cycle (with concurrent pedestrian timing), the delay to the pedestrian would be at a minimum (0 seconds) when the pedestrian arrives during the WALK (or green) interval and a maximum (about 30 to 40 seconds, depending on the specific timing scheme) if the pedestrian arrives at the beginning of the DONT WALK interval. For random arrivals, most pedestrians would be delayed less than 20 seconds, except where longer cycle lengths are used due to heavy traffic volumes. Under heavy traffic volume conditions, a pedestrian yield sign or signal would probably not be appropriate, since the number of safe gaps in traffic would be at a minimum.

Based on the above discussion, several points seem clear regarding the potential effect of the yield sign or signal indications on pedestrian delay. Locations where the pedestrian yield concept would likely result in no substantial effect on pedestrian delay include:

- Locations with poor pedestrian compliance, since pedestrians cross against the light anyway.

- Locations and times when traffic volumes are above 1,000 vehicles per hour since pedestrians would be prevented from crossing, making the yield concept inappropriate.

- Locations with short cycle lengths (i.e., 60 seconds or less), since such cycle lengths normally result in pedestrian delays of 0 to about 40 seconds, which should be a reasonable amount of waiting time for pedestrians.

Situations do exist where the pedestrian yield concept could result in a substantial reduction in pedestrian delay. For example, a signalized location with a long cycle length, with intermittent traffic throughout the day, and a high volume of pedestrians might allow for considerable reduction in pedestrian delay. However, the retiming of the signal to a shorter cycle length, or other alternatives (such as the installation of a pedestrian-actuation device) could be used at intersections to achieve reduced pedestrian delay. Any reduction in pedestrian delay from a yield sign or signal would be at the risk of the pedestrian's judging a safe gap in traffic while crossing against the traffic signal. A rating of fair was given to the pedestrian yield concept for criterion 4.

<u>Criterion 4 - Legality of the Concept</u>

According to the Uniform Vehicle Code, Section 11-501, pedestrians are required to obey traffic control signals, and 36 states have adopted laws which provide for pedestrians to obey traffic control signals at intersections. In nineteen states, local authorities may prohibit pedestrians from crossing against a red or yellow traffic signal. The Uniform Vehicle Code also requires that pedestrian-control signals must be obeyed, although only seven states specifically refer to pedestrian-control signals, and only two of 50 municipal ordinances surveyed in one report require obedience to pedestrian-control signals as well as traffic control signals [8]. In Boulder, Colorado, for example, pedestrians are not required by law to obey pedestrian or traffic signals. Overall, state and local laws and ordinances differ widely with regard to pedestrians and their legal requirements toward traffic control devices, and are often inconsistent with the Uniform Vehicle Code.

The above discussion indicates that the yield pedestrian concept would be contrary to the Uniform Vehicle Code, since it would allow pedestrians to disobey the traffic signals when a pedestrian yield sign or signal message is in effect. This would also be contrary to many state and local ordinances with regard to the yield concept. It should be noted that the general public is not fully aware of the specific ordinances in the Uniform Vehicle Code, or in the various related State and local laws and ordinances. They are even less familiar with such ordinances in other cities which they may visit. A change in the Uniform Vehicle Code and in state and local laws regarding the yield concept is therefore not likely to be widely understood by pedestrians, even with costly and extensive public campaigns and educational programs. Under current laws and ordinances, the pedestrian yield concept may result in significant legal difficulties, and even the field testing of such devices may require laws and ordinances to be violated. Thus, a poor rating was given based on criterion 4.

Criterion 5 - Feasibility of Implementation

To implement a pedestrian yield device, the following problems must be overcome:

- State and local laws must be changed to allow for the concept, as discussed above.
- Warrants must be developed for when and where the devices should be used. For example, under what traffic volume conditions should they be used? For what street widths, pedestrian volume conditions, mix of pedestrians (elderly, young, handicapped), sight distances, vehicle speeds, and related factors would this concept be safe?
- Even after developing specific warrants for their use, many city and state agencies would not be willing to spend their limited funds for installing these devices, particularly at a time when many cities currently have inadequate funding for basic safety and operational improvements and for maintaining their current traffic control devices.
- The added potential danger to pedestrians from the yield concept would make many cities reject its use, particularly since a legal suit could result from a pedestrian accident attributed to the improper application of a pedestrian yield sign or signal.
- The pedestrian delay savings resulting from the use of the pedestrian yield devices would probably be substantial at only a small percentage of signalized intersections.

The feasibility for implementing the pedestrian yield concept in the U.S. seems to be poor at the present time.

Evaluation Summary

Based on the five criteria discussed above, the yield concept for pedestrians does not appear to be a viable solution to the problem of pedestrian disrespect and violation of signals. In particular, the yield concept is of questionable effectiveness and it is, therefore, not a feasible solution at the present time in the U.S., even though pedestrian delay would be reduced at some signalized intersections. The field testing of this concept would also be questionable from a legal standpoint under current laws and ordinances. Thus, the yield concept is not recommended for use as a new type of pedestrian traffic control device.

## Evaluation of Alternatives to the Pedestrian Yield Concept

The major objective of the pedestrian yield concept is to improve pedestrian respect and compliance for pedestrian signals and reduce pedestrian delay. Four other possible alternatives which may be used to meet this objective include:

- Remove or turn off unwarranted pedestrian signal devices
- Use of improved pedestrian actuation devices
- Pedestrian education and public information programs
- Enforcement programs

### Remove or Turn Off Unwarranted Pedestrian Signal Devices

One reason for disrespect of traffic control devices is their excessive use, particularly where they are not warranted. In this case, one option is to remove unwarranted pedestrian signals, which is being accomplished by some city agencies. For example, in Grand Island, Nebraska, a large number of pedestrian signals were removed from the CBD area due to the high level of pedestrian non-compliance [9]. Another possible solution would be to simply turn off the pedestrian signals at night or during off-peak periods. In New Haven, Connecticut, pedestrian signals are turned off at night primarily to save money on electricity, but this action could also reduce the problem of excessive or inappropriate display of the DONT WALK message.

The removal or turning off pedestrian signals at certain times or locations was evaluated in terms of the five criteria discussed previously. The removal or turning off of unwarranted pedestrian signal devices is expected to result in gradual, long-term improvements in pedestrian compliance, since the overuse and misuse of traffic control devices often contributes to the lack of respect for them. Assuming that removing unnecessary pedestrian signals would result in increased compliance, then increased pedestrian safety should result. No legal problems exist with removing unwarranted pedestrian signals, although public and political pressure often hinders such actions.

The feasibility of removing or turning off unwarranted devices varies widely depending on local policies and pressures, but many agencies routinely remove unwarranted devices. Improved MUTCD guidelines are needed for installing (and removing) pedestrian signal indications and also for turning off pedestrian signals at specific times and locations. Removing or turning off unnecessary pedestrian signals could have a small positive effect on pedestrian compliance, but should be used in conjunction with other improvements (increased enforcement, education, etc.) to obtain the best results. Other benefits could also result, including the reduction of operation and maintenance costs associated with pedestrian signals.

Overall, removing or turning off unnecessary pedestrian signal devices would be expected to have some possible benefit to pedestrian safety. This alternative may also have the benefit of reducing unnecessary pedestrian delay plus reducing operational and hardware costs associated with pedestrian signals. This alternative is recommended particularly in conjunction with improved MUTCD guidelines addressing where and when pedestrian signal indications should be utilized.

## Use of Improved Pedestrian Actuation Devices

Pedestrian actuation (push-button) devices have been installed extensively in many cities with the intent of providing more pedestrian-responsive signalization. A detailed discussion and analysis of pedestrian actuated devices was given in Chapter II along with recommended methods of improving their use and effectiveness.

The use of improved pedestrian actuation devices was evaluated in terms of the five criteria discussed earlier, as an alternative to the pedestrian yield concept. The use of improved actuation devices was expected to have a general positive impact on pedestrian use and compliance of pedestrian-actuated signals. This could also result in positive safety impacts. No legal problems exist in improving pedestrian actuation devices. The feasibility of such improvements is good in many localities, although limited funds for signal installation and maintenance and operation are often common constraints. Improvements to pedestrianacutated devices are recommended as one feasible option to pedestrian yield devices.

## Education and Public Information Programs

Educating and informing the public on the meaning and need to obey traffic control devices is being accomplished in numerous cities throughout the U.S. using radio, television, and newspaper advertising, as well as education programs in the schools. Examples of this include [9]:

- Programs related to safety education are common among elementary schools. Such programs as "Officer Friendly", "Officer Bill", use of pamphlets, and in-class discussions by individual teachers are typical examples.

- Public information programs include presentations by local police departments to civic organizations, church groups, and parent-teacher associations. Cities such as Atlanta, Georgia; Concord, California; Erie, Pennsylvania; and Frederick, Maryland, all have had comprehensive public information programs.

- Information through the public media is conducted in cities such as Dallas, Texas, which utilizes 30-second radio/television advertisements on pedestrian safety. The San Diego, California, Union/Tribune has printed and distributed a booklet entitled "You and Traffic" which discusses various types of vehicle and pedestrian safety problems. The city of Seattle, Washington, has developed several television commercials related to pedestrian safety which have been aired over local stations. Details of numerous types of educational programs for pedestrians are given in "Model Pedestrian Safety Program", which was published in 1978 [10].

The use of education and public information was judged based on the five criteria. This alternative has been used in cities throughout the U.S. for many years and can help to promote an awareness of pedestrian safety, pedestrian laws, and traffic control devices for pedestrians and motorists. Information programs are feasible and their continued use is recommended as another alternative to yield signs and signals.

Enforcement Programs

The fourth alternative to the pedestrian yield concept is the use of police enforcement. Examples of cities with effective enforcement programs include:

- San Diego, California, which in 1976 issued 11,046 citations to pedestrians for various violations and 1,634 citations to motorists who violated the right-of-way of pedestrians. Also in that year, the Juvenile Traffic Court issued 2,836 citations to juvenile pedestrians [9].

- In Dallas, Texas, where juvenile pedestrian offenders (14 or under) are often assigned by the courts to write safety-related essay papers, and older violators are sent to a six-hour driver improvement school [9].

- In Milwaukee, Wisconsin, a selective enforcement program is used to concentrate on specific sites, times of day, and days of the week [9].

- In Seattle, Washington, pedestrian violators can pay up to $15 or go to a two-hour lecture on pedestrian safety. Each year, about 11,500 citations are written to violators of pedestrian-related regulations [11].

- In Columbus, Ohio, strict enforcement is noted by the high levels of pedestrian compliance.

- In Florida, an enforcement program was implemented in 1968, which was primarily established for elderly pedestrians [12].

The opposite is true in cities such as Frederick, Maryland, and Sioux Falls, South Dakota, where pedestrian citations have not been backed up by the courts, or in Omaha, Nebraska, where citations are considered to result in bad public relations [9].

Increased police enforcement of pedestrian violators was reviewed as a possible alternative to yield signs or signals. Although occasional enforcement at spot locations is generally not effective, strict long-term, citywide enforcement is believed to contribute to improved signal compliance by pedestrians.

## Conclusions and Recommendations

The purpose of this phase of the study was to investigate the use of yield signs or signals for pedestrians. Seven candidate yield sign and signal devices were developed to convey the intended meaning of the yield concept to pedestrians. The pedestrian yield concept was evaluated in terms of the following criteria:

- Ability to fulfill a need
- Possible safety implications
- Effect on pedestrian delay
- Legality of the concept
- Feasibility of implementation

The need to reduce the high incidence of pedestrian disrespect and non-compliance with traffic and pedestrian signals was considered a critical issue. However, the yield concept was rated poorly in terms of its expected ability to fulfill this need due to: (1) the large number of factors which affect pedestrian compliance; (2) possible confusion which would be caused by this concept; and (3) the limited overall impact of these yield devices on a very complex and widespread problem. The precise safety implications were uncertain, but it was believed that the yield concept could have a detrimental affect on pedestrian accidents, particularly to the young, elderly, and handicapped. An increased nighttime pedestrian safety problem was also considered likely, since the yield device might be used at many locations only during nighttime and other low-volume times.

The pedestrian yield concept would likely result in reduced pedestrian delay, but most locations are not likely to experience substantial reductions in pedestrian delay. At most signalized intersections, pedestrian delay currently ranges from 0 to 30 or 40 seconds, and the reduction in delay due to the yield concept might be at the expense of safety.

The pedestrian yield concept was found to generally conflict with sections of the Uniform Vehicle Code and with local ordinances in many cities and states. The feasibility of the yield concept was judged to be poor based on: (1) conflicts with current laws and ordinances; (2) the doubtful effectiveness of the concept; and (3) limited current funding, which is likely to be spent on higher priorities and on proven types of safety projects.

Overall, the yield concept for pedestrians does not appear to be a viable solution to the problem of pedestrian disrespect and violation of signals. In addition, the field testing of pedestrian yield devices was thought to be impractical from a legal standpoint. Thus, yield devices were not recommended for use as a new type of pedestrian traffic control device.

Alternatives to the yield concept were suggested which could be used to address the intended objective of the yield device, (i.e., increase pedestrian respect and compliance for pedestrian signals). These possible alternatives included:

- Remove or turn off unnecessary pedestrian signal devices
- Use of improved pedestrian actuation devices
- Pedestrian education and public information programs
- Enforcement programs

A review of available information on these four alternatives indicates that any one or more of these alternatives appears to be preferable to the pedestrian yield concept, although little information is available to document their specific effect on pedestrian safety and operations.

Although several alternatives to the pedestrian yield concept were recommended, there are no easy solutions to increasing pedestrian compliance and respect for traffic control devices while minimizing unwarranted pedestrian delay. Within a given community, the adoption and use of only one of the four recommended measures may have little or no permanent effect on pedestrian behavior or safety. However, it is often the combination of several of these efforts that can result in positive impacts on pedestrian behavior, compliance, and safety.

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# CHAPTER V - SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this research study, several major recommendations can be made regarding pedestrian signalization alternatives, as follows:

1. The presence of standard-timed (concurrent) pedestrian signals has no significant effect on pedestrian accidents compared with locations with no pedestrian signals. Therefore, local and state agencies should take a closer look before indiscriminately installing pedestrian signals at all traffic signalized locations. Pedestrian signals are expensive to install and maintain, and they are not justified at many locations.

2. The presence of exclusive-timed, protected pedestrian intervals (including scramble or Barnes' Dance timing) was found to be associated with significantly lower pedestrian accident experience when compared with locations with either concurrent-timed pedestrian signals or no pedestrian signals, particularly for locations with moderate to high pedestrian volumes (more than 1,200 per day). Although exclusive pedestrian crossing intervals may be desirable from a pedestrian safety standpoint, it results in increased pedestrian and vehicular delay and may only be practical at urban intersections with low vehicular volumes.

3. The existing MUTCD Minimum Pedestrian Volume Warrant (Warrant Number 3) 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 Neudorff in 1983 ("Candidate Signal Warrants from Gap Data") also recommended the adoption of this proposed warrant.

4. The School Crossing Warrant (Warrant 4) was found to be acceptable as it currently exists and is recommended for continued use. The Accident Warrant (Warrant 6), and Combination of Warrants (Warrant 8), would be acceptable as they relate to pedestrians, if Warrant 3 is charged, as recommended above.

5. The four requirements for installing pedestrian signal indications (i.e., at school crossings, when Warrant 3 or 6 is met, for exclusive pedestrian crossing phases, etc.) are valid and should be retained in the MUTCD. Of the three criteria where pedestrian signals <u>may</u> be installed, one of these needs revision. The criterion to install a pedestrian signal to "minimize vehicle-pedestrian conflicts" is so general that it is used to justify installation of far too many pedestrian signals in some cities and too few pedestrian signals in other cities.

6. Existing MUTCD guidelines for pedestrian actuation devices are valid and should be retained. However, a slight modification to current MUTCD signs should be allowed which would state the name of the street corresponding to the push-button device. For example, a sign PUSH BUTTON TO CROSS MAIN STREET should be permitted where confusion or improper use exists. Another example is when actuation devices only operate during certain time sof the day. In this case, a sign such as PUSH BUTTON OPERATES ONLY FROM 10 AM TO 4 PM should be used.

7. Further testing of the three-phase pedestrian signal utilizing a DONT START display to indicate the clearance interval is needed to determine whether it should be adopted on a national basis. The three-section DONT START display may possibly be more understandable to pedestrians than the flashing DONT WALK or flashing hand indication, even though it transmits a word message and not a symbolic one. The three sections operate similar to a three-section traffic signal and may be more easily understood, especially since a yellow DONT START indication is used as the clearance interval.

8. A special pedestrian signal explanation sign should be added to the MUTCD. The sign should be installed at intersections in areas where an abnormal amount of pedestrian confusion, misunderstanding, or violations exists relative to pedestrian signals.

9. The flashing WALK signal indication was developed to fulfill the need of warning pedestrians to watch for turning vehicles at certain signalized locations. While the need is a real one, the flashing WALK has been proven to be ineffective in that regard. The flashing WALK should be removed from the MUTCD as soon as possible. Four other sign and signal alternatives were field tested and found to be effective in warning pedestrians and motorists of possible turning conflicts. These alternatives are discussed below.

10. A special regulatory YIELD TO PEDESTRIANS WHEN TURNING sign (directed at motorists) was found to be effective in reducing turning conflicts between pedestrians and motorists when field tested at locations in Milwaukee and Detroit. This sign should be added to the MUTCD for intersection approaches where turning motorists refuse to yield to legally crossing pedestrians.

11. A special warning sign PEDESTRIANS WATCH FOR TURNING VEHICLES should be added to the MUTCD for a limited number of crosswalks (marked or unmarked) where a special hazard to pedestrians exists, such as limited sight distance or high vehicle turning movements. This sign may be used in conjunction with the YIELD TO PEDESTRIANS WHEN TURNING sign aimed at motorists.

12. A special WALK WITH CARE signal indication was found to be effective in reducing pedestrian violations and pedestrian-vehicle conflicts when field tested in three cities. However, this special signal should be used sparingly for optimal effectiveness and only be installed at high pedestrian hazard locations.

13. The pedestrian yield sign or signal which would allow pedestrians to legally cross against the DONT WALK signal at certain locations or times (after yielding to traffic) is not recommended. Such a device is contrary to laws in many states and would likely have a detrimental effect on pedestrian safety.