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Evaluation of Innovative Pedestrian Signalization Alternatives

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ABSTRACT

The purpose of this study was to develop and evaluate innovative pedestrian sign and signal alternatives, particularly those that indicate the clearance interval (in place of the flashing DONT WALK message) and those that warn pedestrians of possible turning vehicles (instead of the flashing WALK message). A total of 41 alternatives were developed, and the 8 judged most promising were evaluated at several sites within 5 U.S. cities. The alternatives were evaluated using before-and-after studies of pedestrian violations and various types of pedestrian-vehicle conflicts. Based on the results of the Z-test analyses of observations at the study sites, several alternatives were recommended for inclusion in the Manual on Uniform Traffic Control Devices for application at intersections with pedestrian safety problems. These included the WALK WITH CARE signal indication, a sign for motorists stating YIELD TO PEDESTRIANS WHEN TURNING (regulatory sign), a pedestrian warning sign stating PEDESTRIANS WATCH FOR TURNING VEHICLES, and a pedestrian signal explanation sign (word and symbolic). A three-section pedestrian signal using DONT START to indicate the clearance interval was recommended for additional testing, but little or no benefit was found for the use of the steady DONT WALK indication for the clearance interval or the flashing WALK indication (to warn pedestrians of turning vehicles).

One of the major pedestrian safety problems in the United States today is the ineffectiveness and confusion associated with pedestrian signal indications. Pedestrians in many cities often do not comply with pedestrian signal indications because of 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).

There could be several reasons for the lack of effectiveness of pedestrian signal indications in commanding respect, improving compliance, or reducing pedestrian accidents. This study addressed the misunderstanding and confusion on the part of pedestrians regarding the meaning of the steady or flashing DONT WALK indication and the steady and flashing WALK 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 (MUTCD) (2). The flashing DONT WALK sign indicates a clearance interval and is 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 between the flashing and the steady DONT WALK indications. Other pedestrians tend to treat the DONT WALK message as only advisory and cross at their own discretion. An accident analysis conducted in an earlier study by Zegeer et al. (3) indicated that in the majority of pedestrian accidents at signalized intersections, the pedestrian had violated the signal message.

A second problem with pedestrian signal indications involves the flashing WALK display. The steady WALK indication is widely used to designate the pedestrian crossing interval, but the flashing WALK indication is used in some jurisdictions to inform pedestrians that vehicles may be turning across their path. When the flashing WALK signal is used, the steady WALK signal 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 signal for the following reasons: (a) many pedestrians do not understand its meaning, (b) their signal display hardware is not easily adapted to providing it, or (c) its use at one location would necessitate its use at all other appropriate locations, which could require major monetary outlays by the agency.

Confusion is common because many pedestrians either do not know the meaning of the flashing WALK signal or believe that any WALK indication (whether flashing or steady) means that they need not look around for cars or use caution. The danger is that a motor vehicle may run through the red light or turn across the crosswalk without yielding to pedestrians. Although pedestrians may be within their rights, they should also exercise caution whenever crossing the street because they are most susceptible to injury or death in the event of an accident with a motor vehicle.

It is believed that these basic problems related to pedestrian signals can be addressed in part by innovative sign and signal alternatives. These alternatives include new sign and signal devices, modifications of existing devices, supplemental devices to enhance the function of the signal, and promotion of improved understanding and respect of the signals.

Figure 1 shows how 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

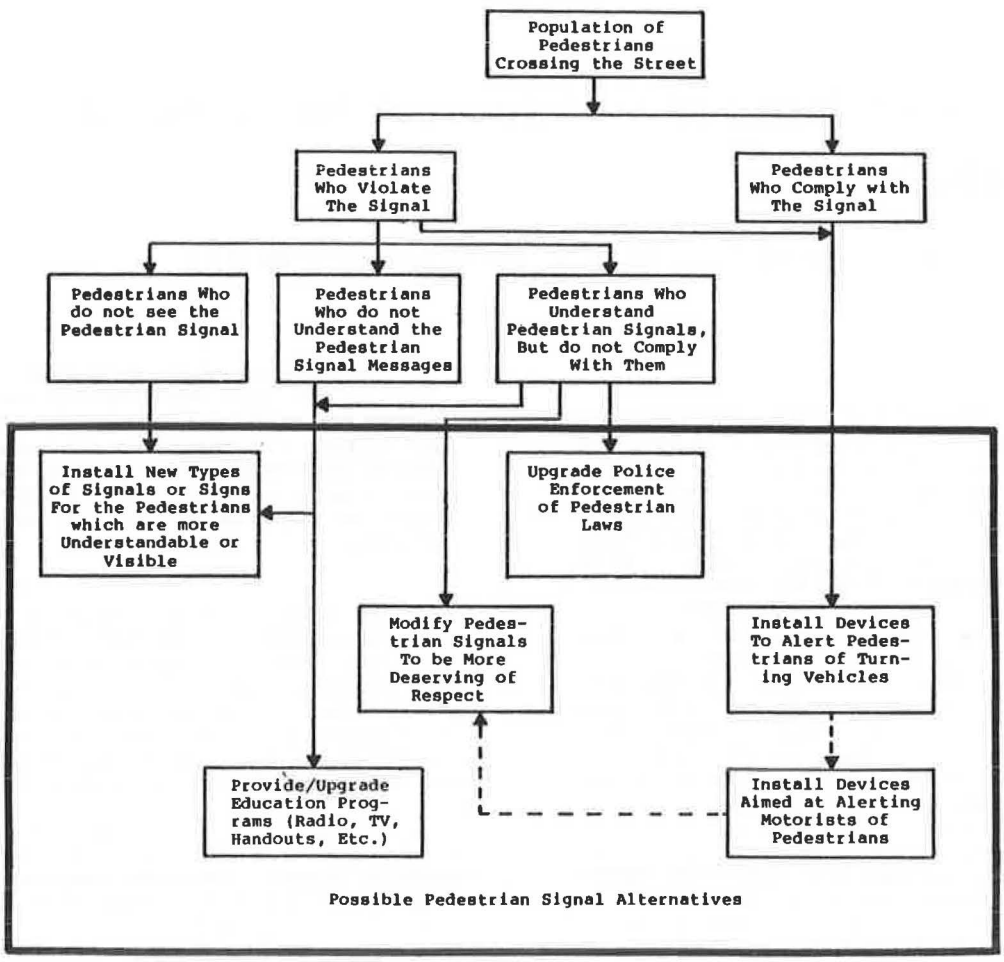

FIGURE 1 Breakdown of pedestrian signal alternatives as they relate to the pedestrian problem.

violate signals do not understand their meaning, do not notice them, or simply choose to disregard them. For pedestrians who intentionally violate the signals, police enforcement or improved pedestrian signs or signals (more demanding of respect) may be appropriate.

This study focused on two situations in which signal alternatives were considered most likely to be effective:

1. Pedestrian clearance: to replace or supplement the flashing DONT WALK indication, and
2. Indication of potential conflicts: to replace or supplement the flashing WALK indication.

It was recognized, however, that other methods must also be considered in efforts to enhance pedestrian safety at signalized intersections. These methods include the following:

1. Enforcement of pedestrian compliance with the signal messages;
2. Enforcement of vehicle compliance with the pedestrian's right-of-way in crosswalks;
3. Public education (i.e., in schools, on radio and TV, and so on) or awareness programs addressing the meaning of pedestrian signals, pedestrian and vehicle laws, and pedestrian behavior; and
4. Changes in the roadway environment through traffic engineering or geometric improvements.

DEVELOPMENT OF PEDESTRIAN SIGNAL ALTERNATIVES

As a part of this study a comprehensive review of the literature and current practices was completed to identify alternatives for indicating the clearance interval and warning of potential conflicts. Subsequently a range of candidate signal alternatives was developed and priority ranked, and the alternatives judged most promising were selected for field testing. The alternatives selected were fabricated and field tested at certain intersections in five cities. Before-and-after analyses of pedestrian compliance and pedestrian-vehicle conflicts were used to evaluate each alternative. The results of these tests are presented in this paper and recommendations are provided for application of the most promising pedestrian signalization alternatives. The alternatives evaluated in this study are described in the following sections.

Selection of Pedestrian Clearance Alternatives

A careful review was conducted of past research and current practices relative to pedestrian clearance indications. Approximately 22 different alternatives for depicting the clearance interval were proposed by various members of the project team for further consideration. These alternatives were refined with inputs from various city, state, and federal officials and other pedestrian signal and safety experts. Detailed descriptions of these alternatives were compiled, which included design features (movement, color, message, size, and location), a sketch or drawing, past use, justification for use, potential advantages and disadvantages, estimated cost of installation, and estimated cost of maintenance and operation. The detailed descriptions were used to rate alternatives in terms of their practicality and expected level of effectiveness. The results were then summarized and recommendations were made concerning the alternatives that should be considered for field testing.

Examples of the 22 experimental devices not selected for testing include education programs (driver education, school education, and so forth), signal displays (various messages on three-section signal heads, color-only lenses, yellow ball for clearance with DONT WALK and WALK messages, and so forth), audible devices (beeping messages, spoken word messages, and so forth), and other alternatives (digital and symbolic countdown devices, variable message displays, pavement messages, and so forth). Such messages were generally rejected for field testing because of their high cost, electronic sophistication, or expected ineffectiveness. Details of these devices are given in the full report on this study by Goodell-Grivas, Inc. (4). The three clearance alternatives selected for field testing and the justification for their selection are described in the following.

Alternative 1: Pedestrian Signal Explanation Sign

An informational sign may be placed on the pedestrian signal pole or other pole near the crosswalk to explain the meaning of the flashing DONT WALK, the steady DONT WALK, and the steady WALK signals (and also the flashing WALK signal, if used). This sign was developed for both word messages and symbolic messages, depending on the type of pedestrian signal at a given site, as shown in Figure 2.

As justification for its use, this alternative will provide continual education and remind pedestrians of the meaning of these indications. Also, a sign placed at the intersection should have the greatest impact on those who need it most. This alternative has a low cost (approximately $10 per sign) and would not require modifications to signal hardware. Although this type of alternative had been used to a limited degree in the past, it was never formally evaluated.

Alternative 2: DONT START Signal Indication

A three-section signal head with an orange DONT WALK indication, a yellow DONT START indication, and a white WALK indication may be used. This pedestrian signal device is shown in Figure 2 (right).

To justify its use, this alternative displays three distinct indications for the different crossing situations, which could eliminate the confusion caused by the flashing DONT WALK signal display. Robertson tested the DONT START indication to replace both the flashing DONT WALK signal (clearance interval) and the steady DONT WALK signal (prohibitive crossing interval), so pedestrians were not shown a separate clearance indication (5). The use of the DONT START signal as a separate clearance display was believed to be more easily understood by pedestrians, because this display for pedestrians would then be comparable with the amber indication of a traffic signal.

Alternative 3: Steady DONT WALK Signal Indication

A steady orange DONT WALK (or a symbolic hand) may be displayed for the clearance interval as well as for the prohibitive crossing period. It is justified on the basis that the flashing mode causes confusion. This option would be to use only the steady WALK and DONT WALK indications. This alternative was estimated to be low in cost and adaptable to existing signal hardware.

FIGURE 2 Devices tested to indicate the clearance interval: symbolic pedestrian signal explanation sign (left) and DONT START signal display (right).

Selection of Alternatives to Indicate Potential Conflicts with Turning Vehicles

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. After the available information had been reviewed, 19 alternatives were developed. These alternatives were developed by using the same procedure as that for indicating the clearance interval. Each alternative was evaluated by the project team as discussed earlier for the clearance alternatives, and recommendations were made for alternatives to be field tested.

Of the 19 candidate devices, examples of those not selected for field testing include motorist signs (motorist warning or turn prohibition signs with or without flashing lights), pedestrian signs (symbolic pedestrian warning signs with or without flashers or loop detectors to detect approaching vehicles), pedestrian signals (pedestrian symbolic or word and signal messages such as CAUTION: TURNING VEHICLES), and other alternatives (reduction of sight obstructions, variable-message pedestrian signal, audible message, and so forth). As discussed previously, each of these devices was considered to be undesirable in terms of cost, practicality, effectiveness, complexity, or other reasons. The alternatives selected are described in the following paragraphs.

Alternative 1: Motorist YIELD Sign

The first alternative is a sign directed toward the motorist that reads: YIELD TO PEDESTRIANS WHEN TURNING. This is a red-and-white triangular sign (similar to a standard YIELD sign), 36 x 36 x 36 in., that points downward and has a pedestrian symbol at the bottom (Figure 3, left).

This alternative is aimed at motorists, who, when turning, are by law supposed to yield the right-of-way to pedestrians. This sign is designed to be conspicuous and easily understandable to motorists. It will be a constant reminder to drivers and has a relatively low cost. Although various agencies have used similar devices, no documented evidence has been found of any previous formal evaluations of these devices.

Alternative 2: Pedestrian Signal Explanation Sign

An informational sign may be used on the pedestrian signal pole that explains the meaning of the flashing WALK, the steady WALK, the flashing DONT WALK, and the steady DONT WALK signals. This device was also tested as an alternative to the clearance indication, as described earlier.

This educational sign provides pedestrians with the intended meaning of the pedestrian signal displays. It is low in cost and would not require modification to existing signal hardware. The effectiveness of this device had not been formally evaluated.

Alternative 3: Pedestrian Warning Sign

A 30 x 30-in. diamond-shaped sign with black letters on a yellow background stating PEDESTRIANS WATCH FOR TURNING VEHICLES may be used (Figure 4, left). Because many pedestrians do not obey or pay attention to pedestrian signals, it was considered beneficial and considerably less expensive to use a sign reminding pedestrians to cross safely rather than to modify the pedestrian signal.

Alternative 4: WALK WITH CARE Signal Indication

A standard three-section signal may be used that has the steady DONT WALK indication for the prohibitive period, a flashing DONT WALK for the clearance interval, and a WALK WITH CARE indication during the crossing interval. The standard white WALK display is used and a yellow WITH CARE display is added at the bottom. This alternative was seen as a means to provide a clear, simple warning of potential vehicle conflicts to pedestrians.

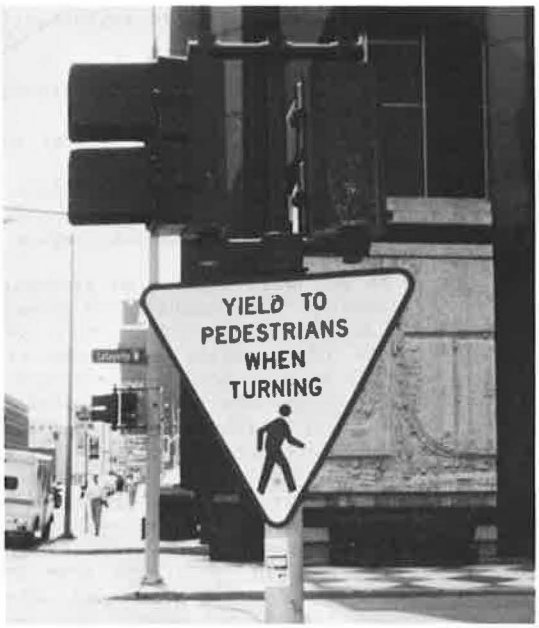

FIGURE 3 Devices tested to indicate potential pedestrian-vehicle conflicts: motorist YIELD sign (left) and word pedestrian signal explanation sign (right).

FIGURE 4 Device tested to indicate potential pedestrian-vehicle conflicts: pedestrian warning sign.

Alternative 5: Flashing WALK Indication

The WALK display flashes at locations where vehicles are permitted to turn through the crosswalk during the WALK interval. The flashing WALK indication is currently allowed in the MUTCD to warn pedestrians of potential vehicular conflicts. This alternative has been used in some cities, and at least one previous evaluation has found this device to be ineffective in warning pedestrians of potential conflicts (5).

EVALUATION OF CANDIDATE PEDESTRIAN SIGNAL ALTERNATIVES

An experimental plan was developed to evaluate the various pedestrian signalization alternatives described previously. This plan addressed the data needs, statistical techniques, sampling requirements, site selection, and data-collection procedures, as described in the following sections.

Data Needs

The evaluation of the various pedestrian signalization alternatives required information to be obtained about pedestrian violations and pedestrian-vehicle conflicts, the nature of traffic conditions at the location, and site features and traffic controls. The specific data needs varied somewhat by the nature of the signalization alternative being tested and its intended purpose. In the following paragraphs the nature of the data required for the evaluation of pedestrian signal alternatives is discussed.

The ultimate goal of each of these experimental devices was to improve pedestrian safety and reduce related accidents. However, accident data are a poor measure of effectiveness (MOE) for testing such devices because of the infrequent occurrence of pedestrian accidents per site, which would necessitate waiting a period of three or more years to obtain sufficient amounts of data after installation of the device. Thus, it was decided to determine whether pedestrian conflicts and violations could be altered to improve safety through various signalization alternatives. The conflict and violation MOEs selected for use in the analysis included the following:

1. Conflict (behavior) measures
   a. Pedestrian hesitation (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

b. Aborted crossing (AC): Pedestrian steps off curb but later reverses direction back to the curb
c. Moving vehicle (MV): Through traffic is moving through the crosswalk within 20 ft of a pedestrian in a traffic lane
d. Right-turning-vehicle (RT) interaction: Pedestrian is in the path and within 20 ft of a right-turning vehicle
e. Left-turning-vehicle (LT) interaction: Pedestrian is in the path and within 20 ft of a left-turning vehicle
f. Running pedestrian conflict (or run-vehicle) (RV): Pedestrian runs in a traffic lane in an effort to avoid a possible collision with a vehicle
g. Run on clearance (RC): Pedestrian runs at onset of clearance interval in response to the change in the signal message
h. Run from turning vehicle (RTV): Pedestrian runs in a traffic lane in response to a turning vehicle or potential turning vehicle

2. Violation (compliance) measures
a. Pedestrian starting on the clearance interval (SC)
b. Pedestrian starting on the prohibited interval (SP)
c. Pedestrian anticipating the WALK signal (starting just before the end of the prohibited crossing) (AW)

Because various pedestrian signalization alternatives with differing functions and objectives were tested, it was necessary to determine the most appropriate operational MOEs for each alternative. For example, the three clearance alternatives are primarily intended to improve pedestrian compliance with pedestrian signals, but they should also have the secondary effect of reducing pedestrian-vehicle conflicts. Some of the devices aimed at the motorist only (such as the motorist YIELD sign) should not affect pedestrian compliance but could affect pedestrian-vehicle conflicts because of changes in driver behavior. A summary of the pedestrian signal alternatives along with the corresponding appropriate MOEs is given in Table 1.

There is a possibility that some types of MOEs will be reduced at the expense of an increase in some seemingly unrelated MOEs. Thus, each sign and signal device was also evaluated by using the following MOEs:

1. Total conflicts with through vehicles: PH, AC, MV, RV, RC;
2. Total turning conflicts: RT and LT interactions, RTV;
3. Total conflicts (conflicts with through and turning vehicles); and
4. Total pedestrian violations: SC, SP, AW.

It was also considered necessary to obtain data related to the vehicular and pedestrian traffic volume at each study site. This information involved counts of vehicles and pedestrians and included vehicle turning movements. This information was required to compute the proportions of pedestrian conflicts and violations and to account for the effects of varying traffic volumes.

In addition to volume and operational data collected before and after installation of each experimental device, site information was also obtained. The information on physical features was used primarily to help select the most appropriate type of experimental device at each site and to assure proper timing, placement, and installation of the device. Site information was also useful in interpreting the results of the analysis, particularly in cases in which a specific device was effective at one site but ineffective at another.

Statistical Analysis Technique

The Z-test for proportions was selected as the statistical test. This test is used to determine whether the proportion of occurrences in one group is significantly different from the proportion of occurrences in a second group. It is applicable to continuous data (proportions) and has three underlying assumptions (6):

1. The distribution is binomial, so that an event either does or does not occur,
2. The observations are independent, and
3. The sample of events is greater than 30 in each sampling period.

TABLE 1 MOEs Selected for Analyzing Each Sign and Signal Alternative

Alternative	Purpose	No. of Sites	MOE Selected
WALK WITH CARE signal indication	Turning-vehicle warning	4	SC, SP, AW, PH, AC, MV, RT interaction, LT interaction, RV, RC, RTV
YIELD TO PEDESTRIANS WHEN TURNING sign	Turning-vehicle warning	4	PH, AC, RT interaction, LT interaction, RTV
PEDESTRIANS WATCH FOR TURNING VEHICLES sign	Turning-vehicle warning	4	PH, AC, RT interaction, LT interaction, RTV
Steady or flashing WALK signal indication	Turning-vehicle warning	5	SC, SP, AW, PH, AC, MV, RT interaction, LT interaction, RV, RC, RTV
DONT START signal indication	Clearance indication	4	SC, SP, AW, PH, AC, MV, RT interaction, LT interaction, RV, RC, RTV
Steady or flashing DONT WALK signal indication	Clearance indication	3	SC, SP, AW, PH, AC, MV, RT interaction, LT interaction, RV, RC, RTV
Pedestrian signal explanation sign	Clearance indication and turning-vehicle warning	5	SC, SP, AW, PH, AC, MV, RT interaction, LT interaction, RV, RC, RTV

Note: Violation measures: SC = start on clearance interval, SP = start on prohibited interval, AW = anticipate WALK signal. Conflict measures: PH = pedestrian hesitation, AC = aborted crossing, MV = moving vehicle, RT interaction = right-turning-vehicle interaction, LT interaction = left-turning-vehicle interaction, RV = running pedestrian conflict, RC = run on clearance, RTV = run from turning vehicle.

In this analysis the events are pedestrian conflicts or violations and an opportunity for an event is a pedestrian crossing.

Sampling Requirements

To allow for proper use of the Z-test for proportions it was necessary to collect a minimum of 30 conflicts and violations at each site. To fulfill this data requirement, it was estimated that 2 to 6 hr of data were required for each test site in each before-and-after period, depending on pedestrian volume levels.

Site Selection

Sites for the collection of data were selected with moderate to high pedestrian volumes (a minimum of approximately 1,000 per day) to ensure adequate samples of events in a reasonable period of time. The sites represented typical situations and were not highly unusual in geometry or traffic control strategy. Attempts were made to select sites that had a pedestrian safety problem, because these sites are prime candidates for improvement.

Acceptable vantage points were needed at the sites to allow discrete observation by using manual data-collection methods or video cameras (i.e., a pole or buildings or other structures near the intersection). In addition, sites were selected to reflect typical applications for the type of device to be tested. For example, the clearance alternatives are most appropriate at sites with moderate to high levels of pedestrian violations and long crossing distances. Alternatives for turning-vehicle conflicts were tested at sites with high turning volumes and high pedestrian volumes.

Some variation was desired in region of the country and in type of city, because the effectiveness of a device may differ considerably depending on local laws and attitudes. Cities also had to be found that were willing to install and maintain the devices until the experimental data could be collected. The cities selected for testing of experimental devices included Detroit, Ann Arbor, and Saginaw, Michigan; Washington, D.C.; and Milwaukee, Wisconsin.

Data-Collection Procedures

A data-collection scheme was developed to allow for the collection of pedestrian behavior and compliance data, traffic and pedestrian volumes, pedestrian-vehicle conflicts, and site characteristics. Two different data-collection plans were used for operational and volume data: video-recording techniques and manual data collection. Video recording was considered particularly desirable in the early stages of data collection at high-volume sites to allow for close quality control of all data, because the film could be viewed repeatedly for checking and verification to guarantee data accuracy. The manual data collection was found to be adequate in the later stages of the project after close control of data collection had been ensured.

Most of the data were collected by using two video cameras, which allowed one camera to film the crosswalk of concern and the other camera to simultaneously film the pedestrian signal message. With a signal mixer, the real-time image of the pedestrian signal message was superimposed into one corner of the video screen, so the pedestrian violations 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 before the WALK signal. A time-image generator was used to superimpose the elapsed time directly onto the screen for use in recording data in 10-min or other intervals.

To collect data, trained technicians viewed the film and recorded the volume, behavior, and conflict data in 10-min intervals. The film was viewed twice, with pedestrian and traffic volumes and turning movements recorded on the first pass and the conflicts and pedestrian violations recorded on the second pass. The data were then entered into a computer file and thoroughly checked for completeness and accuracy.

ANALYSIS OF RESULTS

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 violations and conflicts.

Statistical Analysis

The statistical analysis consisted of a series of Z-tests for proportions to compare several MOEs, such as the percentage of pedestrian violations and conflicts. For example, the percentage of pedestrian conflicts or compliance violations in the before, or base, condition was computed. This percentage was matched with that for the corresponding after, or experimental, period by using the Z-test, and one of the following results was found and illustrated with the corresponding symbol:

- A: significant difference was found in favor of the experimental condition,
- B: significant difference was found in favor of the base condition,
- NC: no significant difference was found between the base and experimental conditions, and
- NA: the MOE was not applicable (for example, on a one-way street approach, conflicts involving right- and left-turning vehicles from other approaches are not applicable; also, some MOEs are not applicable for some types of experimental devices).

The levels of significance used were 0.05 and 0.01.

Because of the small sample sizes of some MOEs, the analysis included MOEs individually and also in the following groups:

1. Total conflicts with through vehicles,
2. Total conflicts with turning vehicles,
3. Total conflicts (through and turning vehicles), and
4. Total pedestrian violations.

These four groups of combined conflicts and violations represent useful information, because they provide a better perspective of the overall effect of a sign or signal. In order to account for changes in traffic volume between the base and experimental periods, 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 were stratified again based on turning volumes for low, medium, and high levels and analyzed for each of these groups. When the results of the Z-tests within each traffic-volume category did not support the overall analysis, differences in traffic volume were assumed to be responsible for at least part of the changes in the MOE.

Pedestrian-Clearance Alternatives

The three pedestrian-clearance alternatives that were field tested in this study included

1. A pedestrian signal explanation sign that defined the intent of the pedestrian signal indications,
2. A three-section pedestrian signal with a steady DONT START indication during the clearance interval, and
3. The steady DONT WALK indication used during the clearance (and prohibitive crossing) interval instead of the flashing DONT WALK indication.

The first two alternatives correspond to the experimental period. The steady DONT WALK indication was used in the base period and the flashing DONT WALK signal in the experimental period. It should be mentioned that these clearance alternatives are intended to improve pedestrian understanding and to reduce violations and associated conflicts. Thus, all types of MOEs listed previously were analyzed before and after the installation of each clearance device. The flashing DONT WALK signal was used as during the base period unless it is stated otherwise. The results of the three alternatives are discussed in the following.

Alternative 1: Pedestrian Signal Explanation Sign

The pedestrian signal explanation signs were tested at two isolated sites in Saginaw, Michigan, where the pedestrian signals used were the symbols for a walking man and a hand (Figure 2, left), and at two sites in Washington, D.C., where the pedestrian word indications WALK or DONT WALK (in addition to the flashing WALK and DONT WALK) were used (Figure 3, right). The signal explanation signs were located at or near the approaches to each crosswalk at the sites and at several nearby signalized crossing locations. The effects of this informational sign on pedestrian violations and conflicts are summarized in Table 2.

At one site in Saginaw, total clearance-related conflicts decreased significantly (0.01 level), and anticipation of WALK signal 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 tested in Saginaw.

At the two sites in Washington, D.C., the sign describing the four word messages was used that explained the flashing WALK as used in that city as well as the flashing DONT WALK. Several significant changes occurred after the signs had been installed. For the two sites combined, a significant improvement resulted in overall pedestrian violations (0.01 level) from 44.4 percent in the base period to 34.7 percent in the experimental 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.

TABLE 2 Results of Installation of Pedestrian Signal Explanation Sign

	Saginaw			Washington		
MOE	Site 1	Site 2	Sites 1 and 2	Site 3	Site 4	Sites 3 and 4
Conflict						
PH	—	—	—	A[a]	B[a]	NC
AC	—	—	—	—	—	—
MV	—	—	—	NC	B[b]	B[b]
RT interaction	NC	NC	NC	A[b]	NA	NA
LT interaction	NC	NC	NC	NA	A[b]	NA
RV	—	—	—	—	B[b]	NC
RC	—	—	—	A[a]	NC	NC
RTV	—	—	—	—	—	—
Total clearance related	NC	A[b]	A[b]	A[b]	B[b]	NC
Total turning related	NC	NC	NC	A[b]	A[b]	A[b]
Total conflicts	NC	NC	NC	A[b]	NC	NC
Violation						
SC	NC	NC	NC	A[b]	B[b]	B[b]
SP	—	—	NC	A[a]	A[b]	A[b]
AW	—	—	A[a]	A[b]	B[b]	A[b]
Total violations	NC	NC	NC	A[b]	A[b]	A[b]

Note: A = significant difference in favor of experimental condition, B = significant difference in favor of base condition, NC = no significant difference between base and experimental conditions, NA = not applicable. A dash indicates insufficient sample size. MOEs are as defined in Table 1.
[a]Significant at the 0.05 level.
[b]Significant at the 0.01 level.

In summary, the pedestrian signal explanation signs did not result in significant reductions in violations or conflicts at the two sites in Saginaw but resulted in a significant decrease in violations and some conflict types at the two sites in Washington. The reason for its increased effectiveness at the Washington sites compared with that at the Saginaw sites is not fully known. It was noted, however, that the violation rate was much higher in the base period at the Washington site (44.4 percent) than at the Saginaw sites (16.2 percent), so there was more room for improvement.

Alternative 2: DONT START Signal Indication

This device was tested at one site in Ann Arbor, Michigan; one site in Washington, D.C.; and at two sites in Milwaukee, Wisconsin. A summary of results for the four sites where the three-section DONT START signal indication was tested is given in Table 3.

At the site in Ann Arbor, no significant changes were observed in clearance-related conflicts, in turning-related conflicts, or in total conflicts. However, pedestrian hesitation increased and moving-vehicle conflicts decreased significantly (0.05 level). Also, the percentage of violations increased significantly (0.05 level) during the experimental period at the Ann Arbor site. City personnel increased the DONT WALK interval by 4 sec during the experimental 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 was found for any group. This implies that the increase in violations in the experimental period was likely because of factors other than the DONT START signal (such as shifts in traffic volume).

At the site tested in Washington, D.C., overall conflicts dropped from 19.3 percent in the base period to 13.0 percent in the experimental 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 in-

TABLE 3 Results of Use of DONT START Signal Indication

MOE	Ann Arbor Site 5	Washington Site 6	Milwaukee Site 7	Milwaukee Site 8	Milwaukee Sites 7 and 8
Conflict					
PH	B[a]	B[b]	–	–	A[b]
AC	–	–	–	–	–
MV	A[a]	–	–	–	–
RT interaction	NC	A[b]	B[a]	NA	NA
LT interaction	NC	NA	NC	NA	NA
RV	–	–	–	–	–
RC	–	NC	–	–	–
RTV	–	–	–	NA	NA
Total clearance related	NC	B[b]	A[b]	A[b]	A[b]
Total turning related	NC	A[b]	NC	NA	NA
Total conflicts	NC	A[b]	A[b]	A[b]	A[b]
Violation					
SC	A[a]	A[b]	A[b]	A[b]	A[b]
SP	B[b]	B[b]	A[b]	A[b]	A[b]
AW	A[b]	A[b]	A[b]	NC	A[b]
Total violations	B[a]	A[b]	A[b]	A[b]	A[b]

Note: A = significant difference in favor of experimental condition, B = significant difference in favor of base condition, NC = no significant difference between base and experimental conditions, NA = not applicable. A dash indicates insufficient sample size. MOEs are as defined in Table 1.
[a]Significant at the 0.05 level.
[b]Significant at the 0.01 level.

creases in a few individual MOEs. A review of Z-tests 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 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 base period to 13.8 percent (331 of 2,392) in the experimental 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, there is strong evidence that the three-section DONT START signal resulted in a significant improvement over the standard flashing DONT WALK display. At three of the four sites, the DONT START display resulted in significantly fewer conflicts and pedestrian violations. At the fourth site (in Ann Arbor, Michigan) no significant changes were experienced. This may have been because of the different signal timing in the experimental period (4 sec of additional DONT WALK signal) and the high percentage of college students (University of Michigan) who crossed. In fact, more than 54 percent of the pedestrians at this site violated the pedestrian signal in the base period, which was a higher violation rate than at any other site where testing was conducted. No type of pedestrian signal would have any effect on a pedestrian population that largely ignores pedestrian signals.

Alternative 3: Steady DONT WALK Versus Flashing DONT WALK Indication

None of the cities selected to test devices agreed to convert their signals to a steady DONT WALK display during the clearance interval for testing purposes (because of 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 base period the steady WALK (permissive interval) and the steady DONT WALK (clearance and prohibitive interval) signals were displayed, and in the experimental period the flashing WALK and DONT WALK signals were displayed as well as the steady DONT WALK signal during the prohibitive crossing interval.

The results of the comparison between steady and flashing DONT WALK signals showed no significant reductions in pedestrian violations, pedestrian hesitations, left-turn conflicts, moving-vehicle conflicts, or total conflicts at the two sites. Left-turning-related conflicts dropped significantly, whereas total clearance-related conflicts increased significantly (0.01 level in each case).

It appears from the analysis at these sites that there is no significant difference in overall conflicts or violations due to flashing signal indications or steady indications for the combined WALK and DONT WALK intervals. This finding basically agrees with Robertson's results, which found that the steady DONT WALK signal had the same effectiveness as the flashing DONT WALK signal, and that the flashing WALK is not an effective means of warning pedestrians about turning vehicles (5). The testing in the Robertson study involved a comparison of the flashing versus the steady WALK signals separately from the flashing versus the steady DONT WALK signals. The results of this study are based on flashing both the WALK and the DONT WALK signals in the experimental period.

Turning-Vehicle Alternatives

The second category of alternatives that were field tested included sign and signal messages to warn pedestrians or motorists or both of possible turning conflicts. The devices tested included

1. Motorist YIELD sign,
2. Pedestrian signal explanation sign,
3. Pedestrian warning sign,
4. WALK WITH CARE signal indication, and
5. Steady versus flashing WALK indication.

The results of the field testing are discussed in the following.

Alternative 1: Motorist YIELD Sign

The YIELD TO PEDESTRIANS WHEN TURNING sign was tested at two sites in Detroit, Michigan, and two sites in Milwaukee, Wisconsin. Because this sign is directed toward motorists approaching an intersection who turn left or right, the only MOEs selected for evaluation purposes are those involving turning vehicles as well as total conflicts. At the Detroit sites, signs were aimed at both left- and right-turning vehicles at one site, but signs were aimed only at right-turners at another site (because 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 left-turn conflicts are not applicable. For the two Detroit sites combined, total turn-related conflicts dropped significantly (21.6 to 15.7 percent), even though these conflicts at one of the sites experienced no significant change. Total conflicts (including all types of behavioral MOEs) also dropped from 25.6 to 19.2 percent, which was significant at the 0.01 level.

At the two Milwaukee sites, 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 for both sites combined (8.8 to 5.8 percent), even though there was no significant change at either site individually. However, there was no significant change in left-turn conflicts. Total turning conflicts were significantly reduced at each of the sites in Milwaukee (0.05 level at one site and 0.01 level at another site), and total conflicts dropped significantly (0.01 level) from 17.9 percent to 11.3 percent at the two sites combined.

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 because of smaller sample sizes and other effects such as the preoccupation 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.

Alternative 2: Pedestrian Signal Explanation Sign

This device was tested at two sites in Washington, D.C., and Saginaw, Michigan, as discussed previously. At the sites in Washington, D.C., the flashing WALK indication was used and the pedestrian signal explanation sign had separate messages for the steady WALK and the flashing WALK signals, as shown in Figure 3 (right). At the two sites in Saginaw symbolic pedestrian signals were used with the steady WALK signal (Figure 2, left). The results of this test (Table 2) showed no significant difference in turn-related conflicts at the Saginaw sites but a significant reduction in turn-related conflicts at the two Washington, D.C., sites.

Alternative 3: Pedestrian Warning Sign

The PEDESTRIANS WATCH FOR TURNING VEHICLES sign was tested at two sites in Detroit and two sites in Milwaukee. This sign was intended to reduce turning-vehicle conflicts by alerting pedestrians to the possibility of turning vehicles. Thus, the MOEs used in analyzing this device were turning conflicts and total conflicts.

Right-turn conflicts at the two Detroit sites dropped significantly (0.01 level) overall, 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 site. There were significant reductions 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, there was a significant reduction in right-turn vehicle conflicts (5.8 to 3.4 percent), although the sample of left-turn conflicts was inadequate to evaluate this type of conflict. 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 no conflicting information.

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-turning-vehicle conflicts. The signs, however, have no proven effect relative to left-turn-related conflicts.

Alternative 4: WALK WITH CARE Signal Indication

The WALK WITH CARE display was tested at one site in Ann Arbor, Michigan; one site in Washington, D.C.; and two sites in Milwaukee, Wisconsin (Table 4). Because the WALK WITH CARE message provided a general warning message to pedestrians, all of the selected MOEs were expected to be related in some way to this device, although the message was expected to have the greatest impact on conflicts related to turning vehicles.

TABLE 4 Results of Use of WALK WITH CARE Signal

MOE	Ann Arbor Site 19	Washington Site 20	Milwaukee Site 21	Milwaukee Site 22	Milwaukee Sites 21 and 22
Conflict					
PH	–	B[a]	–	–	A[a]
AC	–	–	–	–	–
MV	–	–	–	–	–
RT interaction	A[b]	A[b]	A[b]	A[a]	A[b]
LT interaction	–	A[b]	–	–	A[b]
RV	–	–	–	–	–
RC	–	–	–	–	–
RTV	–	–	–	–	–
Total clearance related	A[b]	NC	A[b]	–	A[b]
Total turning related	A[b]	A[b]	A[b]	A[b]	A[b]
Total conflicts	A[b]	A[b]	A[b]	A[b]	A[b]
Violation					
SC	NC	NC	NC	A[b]	A[b]
SP	A[b]	NC	A[b]	A[b]	A[b]
AW	–	A[b]	–	–	–
Total violations	A[b]	A[b]	A[b]	A[b]	A[b]

Note: A = significant difference in favor of experimental condition, B = significant difference in favor of base condition, NC = no significant difference between base and experimental conditions, NA = not applicable. A dash indicates insufficient sample size. MOEs are as defined in Table 1.

[a]Significant at the 0.05 level.

[b]Significant at the 0.01 level.

At the site in Ann Arbor, 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. 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 (Z-value of 14.37 compared with the critical Z-value of 2.58).

At the site in Washington, D.C., there were significant reductions (0.01 level) 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; 23.5 percent of the 1,844 pedestrians were involved in violations during the base period compared with 19.8 percent of the 3,269 pedestrians in the experimental period.

The two sites in Milwaukee with the WALK WITH CARE indication also experienced significant reductions in conflicts and violations. For the two sites combined, there were significant reductions 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 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 previously 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.

The results of field testing at four sites in three cities indicate that the WALK WITH CARE indication is effective in reducing turn-related conflicts as well as pedestrian violations.

Alternative 5: Steady Versus Flashing WALK Indication

The steady WALK display was compared with the flashing WALK display at a total of four sites--two in Washington, D.C., and two in Milwaukee. At the two sites in Washington, D.C., the steady WALK signal (permissive phase) was originally used in conjunction with a steady DONT WALK signal (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 Milwaukee sites were converted from the steady WALK signal (base period) to the flashing WALK mode (experimental period). There was no significant change in pedestrian violations at the two sites combined, although a significant reduction occurred in total conflicts, turning conflicts, and conflicts with through vehicles. However, after the results of the Z-tests had been checked by volume group, these findings were 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 experimental period could also be largely responsible for the results.

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

1. The pedestrian signal explanation sign was found to have no effect at two sites and was effective at two other sites in reducing pedestrian violations and turning conflicts. Its ineffectiveness at the two sites in Saginaw, Michigan, was thought to be the result of little or no pedestrian safety problems (i.e., more than 80 percent pedestrian compliance in the base period) compared with the Washington, D.C., sites (at which there was only 56 percent compliance in the base period).
2. The steady DONT START clearance indication using a three-lens pedestrian signal was found to result in a significant improvement over the flashing DONT WALK display in terms of pedestrian violations and associated clearance-related conflicts at three of the four sites.
3. The steady DONT WALK display for the clearance interval provides no improvement over the flashing DONT WALK signal.
4. The WALK WITH CARE 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 indicate that the WALK WITH CARE message 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 be used at only those intersections with (a) a high incidence of pedestrian accidents involving right- or left-turning vehicles, (b) moderate to high turning volumes and numerous turning-pedestrian conflicts, and (c) a high incidence of pedestrian violations. A specific warrant should be developed for use of this three-lens signal to prevent its overuse, which could reduce its effectiveness.
5. The motorist YIELD sign stating YIELD TO PEDESTRIANS WHEN TURNING was found to be effective in reducing turning conflicts, particularly right-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.
6. The pedestrian warning sign stating PEDESTRIANS WATCH FOR TURNING VEHICLES was also found to be effective in reducing right-turn conflicts. This sign would be appropriate in place of or in conjunction with the YIELD TO PEDESTRIANS WHEN TURNING sign discussed previously. The PEDESTRIANS WATCH FOR TURNING VEHICLES sign could also be applicable to sites with a high incidence or potential for right-turn 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 the steady WALK signals is understood by only about 3 percent of pedestrians (5). The flashing WALK display is not recommended.

Based on the findings of this study, several recommendations are relevant regarding the inclusion of these devices in the MUTCD, as follows:

1. The option for a flashing WALK display should be taken out of the MUTCD, because the flashing display offers no advantage over the steady WALK display and only serves to confuse pedestrians, according to other major studies.
2. The signs 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 turning vehicles, particularly right-turning vehicles interacting with pedestrians.
3. The pedestrian signal explanation sign (both word and symbolic options) should be added to the

MUTCD as information signs to inform pedestrians of the meaning of existing signal messages.

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

5. Because of its beneficial effect at three of four test sites, further testing of the three-section DONT START pedestrian signal indication is justified to determine under what conditions it is effective. However, even if it is more understandable than the flashing DONT WALK signal, its adoption on a national basis may not be practical, because all pedestrian signals would require the addition of a third signal head and additional electronic work.

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Pedestrian Time-Space Concept for Analyzing Corners and Crosswalks

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ABSTRACT

The preliminary version of the new Highway Capacity Manual, Interim Materials on Highway Capacity (Transportation Research Board Circular 212), contains procedures for determining pedestrian levels of service at street corners and in crosswalks. Problems encountered during several applications of the Circular 212 procedures are discussed and a new conceptual approach for analyzing crosswalks and corners is introduced. Based on a time-space concept, this analysis method has several advantages over the Circular 212 procedure. Simply stated, the method is based on developing an estimate of total pedestrian occupancy time for a corner or crosswalk and relating this occupancy value to the available time and space. Average pedestrian occupancies derived from these values are compared with level-of-service criteria to determine relative degrees of convenience. The time-space analysis method and an illustrative problem are presented and compared with the Circular 212 procedure. Additional research to further increase the utility of the time-space technique is discussed.

Increasingly planners and engineers must address the problem of pedestrians at intersections. In the past the primary concern was to provide adequate walk time for safe crossing of the street, and little attention was paid to the volume of pedestrian activity and relative convenience. Vehicular traffic was accommodated first. Sidewalk widths were often reduced to create turning or parking lanes. However, the concentration of workers, shoppers, and visitors in many urban centers is becoming so intense that sidewalks and crosswalks are proving inadequate. Be-