Effects of Pedestrian Signals on Safety, Operations, and Pedestrian Behavior—Literature Review

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During the past 20 years, cities throughout the United States and Europe have installed different types of pedestrian signals in an effort to improve the safety and operational aspects of urban intersections. The purpose of this paper is to summarize the state of the art of pedestrian signals in terms of their effect on safety, operational impacts, and the behavioral aspects of pedestrians. Of the six studies reviewed on pedestrian signals and safety, only one attempted to analyze pedestrian accident data, but the small sample size and infrequency of pedestrian accidents prevented the researchers from making statistically sound conclusions. Other studies used compliance as a safety measure and generally concluded that pedestrian signals result in increased compliance and thus contribute to increased safety, although there was no conclusive proof of increased safety benefits. The five papers reviewed on operational impacts generally indicated that pedestrian signals will almost always increase pedestrian delay, and, at locations that have heavy vehicular volume, overall vehicular delay is also likely to increase. Several authors noted that pedestrians often jump the gun, regardless of the presence or absence of pedestrian signals. Concerning pedestrian signals and behavior, the literature generally indicated that (a) flashing signals were found to be no more or less effective than steady signals and (b) the presence of a clearance interval with a pedestrian signal tends to increase compliance rates. The studies also indicated that pedestrians are likely to ignore signals under low vehicular volume conditions, particularly when clearance intervals exceed the minimum.

Recent research in the area of pedestrian safety has uncovered a number of problems regarding pedestrian signalization alternatives. In some cases, signals installed have failed to command adequate attention of pedestrians. In other cases, they have failed to convey a clear meaning, and yet in others, the intent of the signal has been totally misinterpreted. As a result, questions have been raised by traffic experts regarding the effectiveness of signals in improving the safety and operational features of the intersection.

The current version of the Manual of Uniform Traffic Control Devices (MUTCD) provides general guidelines on the installation of pedestrian signals (1). According to MUTCD, pedestrian signals may be installed under the following circumstances:

1. The crossing is at an established school crossing,
2. The pedestrian cannot see the traffic signal,
3. An exclusive pedestrian crossing interval or phase is provided at one or more crossings,
4. Any volume of pedestrian activity requires the use of a pedestrian clearance indication to minimize pedestrian-vehicle conflicts and assist pedestrians in making a safe crossing,
5. Multiphase intersections cause confusion to pedestrians, and
6. Pedestrians cross part of a street to an island during an interval and will not have sufficient time to cross another part of the street.

MUTCD describes a total of eight signal warrants, four of which have direct or indirect pedestrian implications. These are the pedestrian volume warrant, the school crossing warrant, the accident warrant, and the combination of warrants. However, consideration of pedestrian factors in actual signal installation is not very common. For example, a study conducted for the National Cooperative Highway Research Program (NCHRP) found that, out of a sample survey, only 21.2 percent of the traffic signals were installed based on warrants that consider pedestrian factors and only 1.3 percent of the traffic signals were installed based on the pedestrian volume warrant (2).

The basic types of signal timing for pedestrian signals include (as provided in MUTCD)

1. Concurrent or standard timing (where the pedestrians walk concurrently with moving traffic),
2. Early release (where pedestrians are allowed to leave the curb before traffic is allowed to turn),
3. Late release (which holds pedestrians until a portion of the phase is given to turning vehicles), and
4. Exclusive pedestrian interval, where pedestrians have a protected crossing interval.

Scramble or Barnes dance timing is a form of exclusive timing where pedestrians are allowed to cross diagonally across an intersection.

In order to justify the installation and use of pedestrian signals, it is important to know their effects on safety, operations, and behavior. The use of accident data is considered the most desirable method of measuring the safety effectiveness of countermeasures. However, when accident data are inadequate or not available, indirect measures must be used. One promising method of assessing the safety benefits of pedestrian countermeasures is the use of behavioral observations. Nonaccident behavioral analysis has been used in the past for identifying unsafe pedestrian actions and for evaluating the effectiveness of pedestrian countermeasures (3). In a few other studies, researchers have attempted to evaluate the operational effects of pedestrian signals and have used different types of delay measures to determine whether pedestrian signals or different pedestrian signal-timing schemes will result in operational improvements.

The purpose of this paper is to review research studies on pedestrian signals to obtain a better understanding of (a) whether pedestrians signals improve pedestrian safety, (b) whether any operational improvements result from these signals, and (c) whether or not pedestrian signals result in better compliance.

Several criteria were used to review the articles related to pedestrian signals, including

1. Appropriateness of the analysis methods,
2. Adequacy of the data base used,
3. Validity of the conclusions reached, and
4. Overall applicability of the study results.

SAFETY IMPACTS OF PEDESTRIAN SIGNALS

A number of technical articles were reviewed in the general area of pedestrian safety and signals.

Fleig and Duffy

Fleig and Duffy, in a study in New York City during the early 1960s, examined behavioral data at a given intersection and limited accident data at a number of urban intersections before and after the installation of pedestrian signals (4). Pedestrian behavior, rather than accidents, was used as a primary measure of effectiveness of signals because of the problem of sample size and necessary lead time.

The authors identified a number of pedestrian actions or violations as unsafe acts and determined the trends in these unsafe acts before and after the installation of a pedestrian signal with a Barnes dance (scramble) phasing. For the accident study, they analyzed the pedestrian accident data at a total of 11 intersections one year before and one year after the installation of the pedestrian signals [see table below (4)].

Intersection No.	No. of Pedestrian Accidents: 1 Year Prior to Signal Installation	1 Year After Signal Installation
1	7	4
2	2	4
3	1	0
4	2	1
5	3	1
6	2	4
7	3	0
8	1	3
9	1	1
10	3	3
11	2	4
Total	27	25

They found no significant reduction in the proportion of unsafe acts before and after the installation of pedestrian signals. Based on this evidence, the authors concluded that pedestrian signals are not an effective method for reducing pedestrian accidents.

The number of pedestrian accidents at the 11 intersections studied were reduced slightly (27 versus 25) after installation of the pedestrian signals. However, the small sample of intersections and the low number of accidents in the sample did not allow for a conclusive statistical analysis. This limitation was also recognized by the authors.

The use of several years of accident data, a large number of sites, and a better experimental design (i.e., use of randomized control sites, comparison sites, or trend analysis) would have greatly enhanced the experimental plan and could have resulted in some important findings relative to pedestrian signals and their effect on safety. Another way to have enhanced the study would have been to review each accident report carefully to omit any pedestrian accidents that are totally unrelated to the pedestrian signals. For example, accidents that are attributable to unrelated factors such as vehicle failure or drunk driving should be screened out in such an analysis. The authors do not report on any such screening effort. This study, however, is one of the few that attempted to analyze actual pedestrian accident data to assess the effectiveness of pedestrian signals. The study does not show any conclusive evidence about either a positive or a negative effect of pedestrian signals with respect to accidents.

Mortimer

Mortimer compared the compliance rates of pedestrian crossings at intersections with and without pedestrians signals (5). His methodology consisted of (a) identifying similar signal-controlled intersections with and without pedestrian signal (WALK and DON'T WALK) indications, (b) collecting data at these intersections on pedestrian compliance as well as on the incidence of successful completion of crossing, and (c) developing two types of hazard indices and other statistics on pedestrian crossings. Mortimer found that

1. Better signal compliance was found at intersections with pedestrian signals than at those without them;
2. Fewer illegal starts and more successful crossings were made at intersections with pedestrian signals than at those without pedestrian signals;
3. Hazard-index values calculated for intersections with pedestrian signals were slightly lower than those calculated for intersections without pedestrian signals;
4. Potentially serious pedestrian-vehicle conflicts were reduced substantially at intersections with pedestrian signals; and
5. The use of pedestrian crossings was instrumental in improving compliance and in providing more information to pedestrians, which resulted in more comfortable crossings and fewer crossing hazards.

This study provides some useful information regarding pedestrian compliance, specifically in comparing intersections with and without pedestrian signals. However, without any known quantifiable relation between pedestrian compliance and accidents, the true effects of pedestrian signals on safety (i.e., pedestrian accidents) cannot be determined.

Skelton, Bruce, and Trenchard

Skelton, Bruce, and Trenchard, in a study related to the effectiveness of pelican crossings, conducted surveys at a number of sites in the city of Newcastle-upon-Tyne and in a town in rural Northumberland, England (6). Pelican crossings are pedestrian-actuated crossings, used extensively in England, Australia, and some European countries, in which the pedestrian phase is initiated by a pedestrian push button. Zebra crossings are crossings that have alternate black and white stripes and are occasionally marked with flashing beacons. The study did not analyze any accident, operational, or compliance data but mainly focused on an opinion survey among pedestrians on the understanding and effectiveness of pelican crossings. The study concluded that the general public (pedestrians as well as drivers) lacked understanding of the way in which pelican crossings were designed to function. The study recommended that, if the potential of the crossing devices are to be fully realized, significant operational and design improvements must be made.

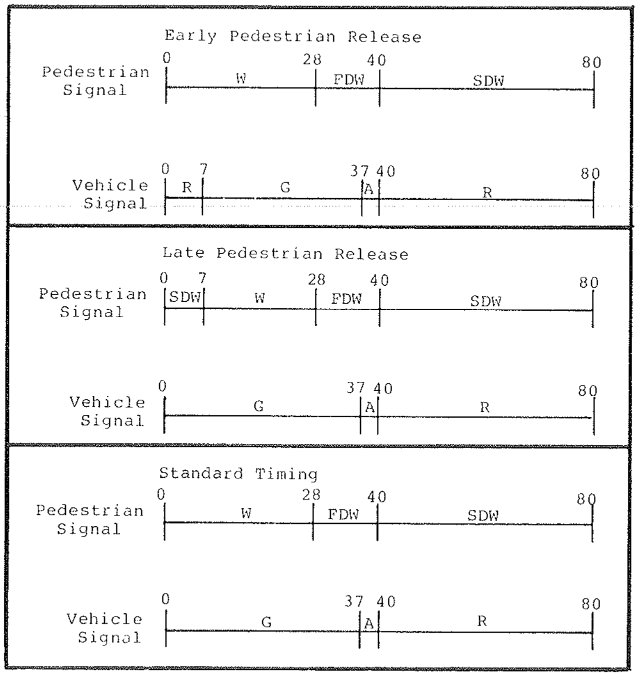
The above study cannot necessarily be categorized as a safety study, since it does not deal with any accident or compliance data. However, it provides information relative to the effectiveness of new or innovative control devices and public acceptability. The study suggests that adequate publicity and appropriate placement are necessary prerequisites to the successful use of any new control device. The message of these devices must be properly received and understood by the motorists and pedestrians if the intended purpose is to be achieved.

Abrams and Smith

Abrams and Smith (7), in their effort to address the safety (and delay) aspects of pedestrian signals, analyzed three types of signal phasing (i.e., early release, late release, and scramble timing) [Figure 1 (7)]. The authors performed compliance studies in Sioux City, Iowa, and concluded that

1. The early release of pedestrians may provide a measure of additional safety, but the benefits were not precisely determined;

Figure 1. Timing used in the analyses of early and late release of pedestrians.



Note: W = WALK interval; FDW = flashing DONT WALK interval; SDW = solid DONT WALK interval; G = green indication; A = amber indication; and R = red indication

2. Higher compliance rates associated with the late-release technique are indicative of increased pedestrian safety; and

3. Scramble timing has the capability of increasing pedestrian safety by completely eliminating pedestrian-vehicular conflict; however, violation rates for scramble timing were found to be higher, particularly at narrow streets.

The authors' postulated association between safety and compliance appears to be based primarily on judgmental factors as opposed to any specific data analysis. The higher violation rates at scramble-timed intersections (i.e., where an exclusive pedestrian phase exists with diagonal crossings permitted) is indicative of the higher pedestrian delay generally associated with these locations. This study provides useful information regarding pedestrian behavior and compliance relative to various pedestrian signal-timing schemes (i.e., early release, late release, standard, and scramble timing), which may or may not be indicative of pedestrian safety.

Williams

Williams discussed the evolution of the pelican concept in England and in Australia and summarized the findings and experiences of different researchers about safety, operation, and behavior (8). The discussion is primarily oriented toward a comparison with its predecessor, the zebra crossing. The author mentions that uncontrolled zebra crossings, originally introduced in 1951, were reported to cause delay and congestion in heavy vehicle and pedestrian flows. Pelican crossings appeared to present considerable advantages over zebra crossings. Williams also mentions that at least one study in Australia found that accidents decreased by 60 percent at a sample of pelican crossings that were originally zebra crossings.

Based on these findings, Williams suggests that it is not possible to definitely conclude that pelican crossings significantly increase pedestrian safety. He mentions that, in most of the sites where positive safety benefits were indicated, the results appear to be masked by the presence of other factors. A number of other countermeasures were installed at these sites (e.g., antiskid surfacing and guardrails), and the effects of these treatments are very difficult to isolate from the overall safety effect of the pelicans. Although the studies reported by Williams do not provide conclusive evidence of the positive safety benefits of pelican crossings, there was also no indication of any adverse effect of the devices.

Inwood and Grayson

Inwood and Grayson, in a study conducted for the Transport and Road Research Laboratory, England, analyzed injury accident data, pedestrian counts, and vehicle flows for lengths of road on and near pedestrian crossings (9). The prime objective of this study was to compare pedestrian accident rates at zebra and pelican crossings. The candidate crossings were located in similar conditions at sites throughout England and were selected on the basis of good visibility and not being too close to busy intersections. The study showed no evidence of a difference in pedestrian accident rates between pelican and zebra crossings. However, pelican crossings tended to have a lower total injury accident rate than zebras when the road length in the vicinity of the crossings is taken into account.

It appears that push-button signals (pelicans) are not any more effective than pavement markings with flashing beacons (zebras) in reducing pedestrian accidents. However, when injury accidents are considered, pedestrian-actuated signal crossings are more effective than zebra crossings.

OPERATIONAL IMPACTS OF PEDESTRIAN SIGNALS

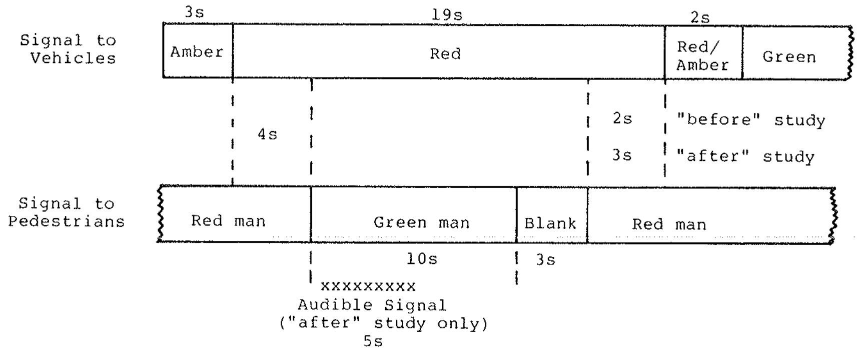
The impact of pedestrian signals on traffic operation at or near urban intersections has been studied by a number of researchers. Traffic engineers, in particular, have been concerned about the possible effect of pedestrian signals on delay to pedestrians and motorists and on intersection capacity.

Abrams and Smith

Abrams and Smith evaluated the delay effects of three types of pedestrian signals--early release, late release, and scramble timing--relative to standard (concurrent) combined vehicle-pedestrian interval (7). They used time-lapse photography to record events and computed delay from the recorded data. For this study, delay was defined as "the difference between the time required for a right-turning movement with pedestrians in the crosswalk and the time required for a right-turning movement without pedestrians in the crosswalk."

The study showed that the standard (concurrent) pedestrian-vehicle interval will almost always result in lower overall pedestrian and vehicle delay than will other pedestrian signal-timing schemes (i.e., scramble, early release, or late release). The only exception to this occurs in cases of long queues of vehicles in a right-turn lane (or left-turn lane of a one-way street) caused by pedestrian-vehicle conflicts. The specific conclusions were that the early-release technique always increases total intersection delay. The late-release technique may result in a reduction of total intersection delay only under certain combinations of volume

Figure 2. Signal phasing diagram used by Wilson.



and geometrics. Scramble timing always increases pedestrian delay.

Pretty

Pretty analyzed the relative delays to pedestrians and vehicles with two methods of signal-timing schemes: (a) exclusive pedestrian phase (scramble timing) and (b) shared-phase (concurrent) with motor vehicles (10). He used a deterministic numerical technique [developed by Miller (11)] that is commonly used in Australia to compute bicycle crossing intervals, signal settings, and delays. He estimated pedestrian and vehicle delays for varying cycle lengths that corresponded to the two types of signal control timing schemes. Pretty also assumed that pedestrians arrive at a uniform rate throughout each cycle and that the number of pedestrians desiring to cross both streets is twice the number that cross one street. His assumption of pedestrian arrivals contradicts assumptions made by some researchers in the United States.

The numerical examples presented by Pretty do not lend themselves to a direct comparison between the two types of control. It appears from the results presented that scramble timing increases both pedestrian and vehicular delay significantly although the signal parameters (e.g., cycle length) analyzed in the two cases are different. The author does not address the question of whether the differences in the total intersection delay are due to the types of control or to the signal parameters. Pretty also shows that pedestrians are always likely to benefit from shorter cycle lengths (due to reduced pedestrian delay) and that increased pedestrian volume significantly increases pedestrian delay.

Smith

Smith discusses problems associated with the lack of consistency in the timing of pedestrian clearance intervals as well as different phasing schemes (12). He computed both the vehicle right-turn delays and pedestrian delays for two hypothesized timing schemes: (a) minimum clearance alternative (i.e., the clearance interval is only long enough to cross the street that provides a longer WALK interval) and (b) minimum WALK alternative (i.e., the WALK interval is only a few seconds long and a longer flashing DON'T WALK interval exists) (12).

Vehicular right-turn delay was computed by using a relation that was developed from data collected for 68 h of time-lapse photography at intersection approaches in Washington, D.C.; Phoenix, Arizona; Akron, Ohio; and Cambridge, Massachusetts. Pedestrian delay was calculated by using a bilevel arrival rate with the assumption that such arrivals are highest during and just prior to the WALK interval and approximately half that rate following the WALK interval.

Smith's study showed that the minimum WALK alternative reduces vehicle right-turn delay because of no interference between pedestrians and vehicles after the initial platoon of vehicles has crossed the street. Smith also concluded that the increase in pedestrian delay of the minimum WALK alternative over the others was significantly greater than the decrease in vehicle right-turn delay. He concluded that clearance intervals longer than the minimum generally increase overall intersection delay.

Wilson

Wilson, in his study conducted at the Transport and Road Research Laboratory, England, assessed the operational and behavioral effects of installing an audible signal for pedestrians at intersections that have pedestrian indications (13). The concept of an audible pedestrian signal has been introduced in recent years as a possible aid to blind or visually impaired pedestrians. A speaker, attached to the pedestrian signal, emits a beeping, buzzing, or chirping noise during certain signal phases to supplement the visual pedestrian display. The signal phasing diagram used by Wilson is shown in Figure 2 (13). He used time-lapse photography to record adult pedestrian crossings at a signalized intersection before and after the installation of the audible signal. Wilson's major conclusions are as follows:

1. Pedestrian delay at the curb was not affected by the installation of the audible signal;
2. Time taken to cross the road by pedestrians crossing during the "green man" phase decreased by 5 percent;
3. For those pedestrians who started to cross during the green man phase, a significant reduction was obtained in the proportion who failed to complete their crossing before the vehicle green signal began; and
4. Significant differences in pedestrian behavior and delay were observed between the before and after data that seemed to be indicative of positive safety effects of audible signals.

Audible signals might be particularly beneficial to visually handicapped pedestrians. On the other hand, these signals may also cause potential confusion to pedestrians regarding which direction to cross. One argument against the use of audible pedestrian signals for handicapped pedestrians is that, unless they are used everywhere, they may cause more problems than they solve, since the blind cannot always count on having the audible message at every intersection. The paper by Wilson points out small but statistically significant reductions in delay to nonhandicapped pedestrians.

PEDESTRIAN SIGNALS AND BEHAVIOR

The possible effects of pedestrian signals on the behavior of pedestrians and motorists have been a topic of research among traffic engineers and psychologists for a number of years. The aspect of such behavioral studies is of importance to many safety analysts because, in the absence of sufficient accident data, behavioral changes associated with pedestrian signals may often be regarded as indicative of safety benefits or disbenefits.

Williams

Williams discussed pedestrian behavior relative to pelican crossings in England (8). His paper included a review of numerous papers on the subject. Based on his findings, Williams makes the general conclusion that pedestrians tend to accept natural gaps in traffic rather than wait for the signal to provide a protected crossing interval. This behavior may not be harmful if pedestrians accept only safe gaps. However, unnecessary motorist delays (and unnecessary risks to pedestrians) may be caused by pedestrians who cross on red signals after activating the pelican signal.

Smith

Smith discussed the importance of compliance to signal indications by pedestrians and suggests that the purpose of a pedestrian clearance interval is likely to be defeated if such clearance intervals are longer than the minimum required intervals (12). Studies were performed at two intersections each in the cities of Washington, D.C.; Phoenix, Arizona; and Buffalo, New York, to determine pedestrian compliance to a flashing DON'T WALK interval that was longer than the minimum clearance. At each intersection several timing schemes were installed, which ranged from the minimum clearance interval to long clearance intervals, and compliance data were collected.

The data showed a trend of lower compliance (lowest percentage begins to walk during the WALK interval) for those timing alternatives that have the least amount of time allocated to the WALK interval (longer clearance intervals). Pedestrians appeared to show a higher degree of disregard for flashing DON'T WALK clearance intervals that are longer than the minimum. The author states that the reason for the decrease in compliance for clearance intervals longer than the minimum appears to be that average pedestrians are not fooled into thinking they have less time to cross the street before vehicles in the cross street are released.

Based on these results, pedestrian signals should generally be set with the minimum clearance interval and the WALK interval should not be less than some minimum period. Of course, when setting any clearance interval, care should be taken to allow adequate time for slower-than-average walkers (i.e., elderly and handicapped pedestrians).

Robertson

Robertson, in a paper that was developed as a part of a Federal Highway Administration (FHWA) study on pedestrian safety, reported on user preference and understanding of symbol displays (as opposed to word messages) and on the field testing and evaluation of these displays (14). Five preference surveys were conducted: two of traffic engineers and safety experts, two of pedestrians in 12 cities, and one of school children.

The author discusses different conceptual forms of symbolic signal displays and presents the result of each preference survey with appropriate details. The data show a great deal of difference in opinion and response to symbols and colors among engineers, adult pedestrians, and school children. Overall, the walking man symbol (WALK phase) message and the hand signal (DON'T WALK interval) were recommended.

Kyle

Kyle attempted to evaluate the effectiveness of dynamic pedestrian signals in controlling pedestrian movements (15). A major difference between a conventional signal and the dynamic signal is that a conventional signal is likely to change to DON'T WALK while pedestrians are in the crosswalk. The dynamic signal allows the pedestrian to see the WALK indication the entire time he or she is crossing.

In his study, Kyle used a before-after experimental design in which pedestrian observation data were collected at two experimental and two control intersections. Time-lapse photography and manual counting methods were used to record pedestrian movements at the candidate locations in the Champaign, Illinois, urban area. Kyle's study showed that the dynamic pedestrian signal tended to reduce the number of illegal pedestrian movements in the intersection area. A greater percentage of pedestrians crossed during the clearance interval in the after phase when the dynamic signal was in operation than during the before phase. However, other problems encountered with the mechanics of dynamic signals hampered their use (15).

Stoddard

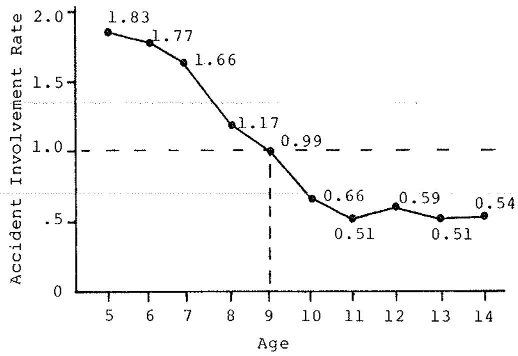
Stoddard also conducted a study, similar to that of Kyle, to assess the effectiveness of dynamic pedestrian signals in controlling pedestrian traffic (16). Two types of analyses were conducted. First, a comparison of before and after reactions was conducted by using a pedestrian compliance count at a specified intersection. Second, pedestrians were interviewed to determine pedestrian reaction to the new type of signal. A total of 558 pedestrian interviews were conducted two months after the new signals were installed.

The study showed that a significant number of pedestrians were cleared from the crosswalk that had the dynamic signal, and the author recommended that this type of pedestrian control would be appropriate for intersections where the pedestrian interval is short or the crosswalk distances are relatively long. The interviews showed that only a small percentage of the pedestrians are likely to be confused by the new signal (16).

Retzko and Androsch

Retzko and Androsch studied pedestrian behavior at signalized intersections in Dusseldorf and a few other cities in the Federal Republic of Germany (17). The authors investigated pedestrian behavior at a number of signalized intersections with and without an amber phase in the pedestrian signals. Data were collected on pedestrian walking patterns and at 24 crosswalks of similar geometrics for a total of 5000 cycles during 1972-1973. The authors found that the presence of an amber phase generally resulted in better pedestrian compliance. Furthermore, in the absence of an amber phase, pedestrians tended to walk against the red. Based on this finding, the authors recommended the installation of an amber phase (clearance interval) for pedestrian signals.

Figure 3. School trip pedestrian accident involvement rate of students by age.



Based on 1,910 school trip accidents.

Sterling

Sterling attempted to quantify pedestrian reaction to flashing WALK as well as the steady WALK indications (18). He describes two measurable aspects of pedestrian attributes as reflective of pedestrian behavior:

1. Observation rate--the percentage of legal crossings and
2. Conflict rate--the percentage of crossings with specifically defined interruptions.

The quantification of these variables was used to develop conclusions with respect to pedestrian reaction regarding the flashing WALK and steady WALK intervals.

Sterling collected pedestrian behavior data at locations that have a high concentration of pedestrian and vehicular volume during twelve 1-h periods. In virtually all comparisons, the reaction to flashing WALK was less favorable than that to steady WALK. Although the percentage difference in conflict rate is not so drastic as in the compliance rate, the effectiveness of flashing WALK signals appears questionable from these results. The specific conclusions of this study are that a significantly higher percentage of legal crossings occurred with the steady WALK as compared with the flashing WALK. A significantly higher percentage of illegal conflict crossings occurred with the flashing WALK than with the steady WALK.

The results of this study point out the general misunderstanding of the flashing WALK (or flashing man) indication as a warning to pedestrians to watch for turning vehicles. Many states still do not use the flashing walk concept either because they have reservations about its value or because some of their signal hardware is not easily adaptable to a flashing mode.

Jennings and Others

Jennings and others studied pedestrian behavior at a number of signalized locations that had experienced a large number of pedestrian accidents in the City of Portland (19). The authors used video recording techniques to observe pedestrian behavior at signalized intersections. They found that pedestrian behavior could be described in terms of its unsafe aspects:

> Numerous pedestrians do not obey the DON'T WALK signal. Numerous pedestrians do not look in the presence of either a WALK or DON'T 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.

This study did not directly address the question of behavioral changes associated with the addition of pedestrian signals, but it provides useful information. The study indicates that unsafe behavior is associated with intersections that experience high frequencies of pedestrian accidents. However, the above inference can be questioned, since the authors did not report on any effort to collect similar behavioral data at intersections with little or no history of pedestrian accidents and did not test how pedestrian behavior at these intersections compared with behavior at the original intersections studied.

Reiss

Reiss discussed the behavior of young pedestrians (ages 5-14) during street crossings for typical school trips (20,21). Students in the eastern United States were observed walking to school and were then surveyed regarding their behavior and the underlying knowledge associated with their habits as pedestrians. By using accident and age distribution data collected by the American Automobile Association, Reiss showed that (20, 21) "there is a near-monotonic relationship between age and accident involvement rate for the 5 to 14 year old population." The youngest students are considerably over-represented in the school trip accident data, as illustrated in Figure 3 (20).

Reiss' study shows that, with an increase in age, a greater proportion of the students will cross with the green signal. This increased knowledge of traffic control devices with student age closely matches the decreasing rate of student involvement in accidents. Further, students' propensity toward taking risks may increase with age. However, as the accident data indicate, this may be offset by improved knowledge and ability to interpret the signal indication with increasing age and by an increased ability of the matured pedestrians to take evasive actions in cases of an approaching vehicle.

Robertson

Robertson analyzed pedestrian behavior, compliance, and understanding for different types of word messages (22). The author reports on three experiments conducted that included (a) comparison of steady DON'T WALK to flashing DON'T WALK, (b) comparison of DON'T START with DON'T WALK, and (c) comparison of steady WALK with flashing WALK messages. All three experiments were conducted simultaneously in Buffalo, New York, and Phoenix. A before and after study design was employed to conduct the experiments. It was found that

1. A steady DON'T WALK clearance display appears to have the same effectiveness as a flashing DON'T WALK clearance display. Evidence is not sufficient to conclude that a steady clearance is better than a flashing clearance.
2. The DON'T START message offers little or no improvement over the current DON'T WALK message.
3. A flashing WALK is not an effective means of warning pedestrians about turning vehicles.

CONCLUSIONS

Research in the area of pedestrian safety has gained considerable prominence over the last decade. Pedestrians have historically accounted for a large

Table 1. Summary of pedestrian signal studies in the safety area.

Authors	Location of Study	Use of Accident Data	Use of Compliance Data	General Conclusion
Abrams and Smith	Sioux City, Iowa	No	Yes	Improve compliance observed since installation of pedestrian signals
Mortimer	Eastern Michigan University	No	Yes	Decrease in conflict, illegal starts, and hazard-index values since the installation of pedestrian signals
Fleig and Duffy	New York	Yes, limited	Yes	A small reduction in pedestrian accidents at 11 intersections does not provide statistically reliable conclusions; no significant reduction in unsafe acts noticed
Inwood and Grayson	England	Yes	No	No significant difference in pedestrian accidents between zebra and pelican intersections
Skelton and Trenchard	England	No	No	Opinion survey indicated a lack of understanding of operating characteristic of pelican crossings
Williams	England and Australia	Yes	No	General reduction in pedestrian accidents observed with installation of pelican signals; however, presence of other countermeasures make it difficult to isolate the effect of pelican signals

number of highway fatalities. The occurrence of most of these pedestrian fatalities at or near urban intersections has led traffic experts to believe that the use of pedestrian signals would improve pedestrian safety. A number of cities have experimented with this concept and have installed different types of pedestrian signals that have included word messages, symbolic messages, flashing and steady signal indications, and even audible messages for pedestrians.

The overall purpose of this paper was to ascertain exactly what is known regarding the effects of pedestrian signals on (a) safety, (b) operation, and (c) behavioral aspects of pedestrians.

Pedestrian Signals and Safety

Six papers were reviewed that addressed the question of the relation between safety and pedestrian signals. Three of these were related to experiences in the United States, and the other three were on the experience of pelican crossings in England and Australia. Critical features of these studies are summarized in Table 1. This table shows that only one study attempted to analyze accident data [Fleig and Duffy (4)], but data limitations prevented the researchers from obtaining statistically sound results. If pedestrian compliance is indeed a true measure of safety (as postulated by many researchers), then pedestrian signals could possibly contribute to increased pedestrian safety. However, none of the studies in the literature developed a quantifiable relation between pedestrian accident experience and pedestrian behavior and compliance.

To some extent, experiences with pelican crossings in England and Australia reveal similar trends. Again, the nonavailability of accident data posed major problems for the researchers. None of the studies showed indications of adverse safety effects of pelican crossings. However, in cases where definite positive effects were discerned (after the installation of pelican crossings), it was difficult to isolate the singular effect of pelican crossings from other countermeasures installed. The overall general conclusion that can be made from these studies are that, although there are indications from compliance and behavior data that pedestrian signals could be beneficial in some instances, there is no conclusive evidence from the literature to support the contention that pedestrian signals increase pedestrian safety. The lack of understanding and uniformity of pedestrian signals may be one of the reasons for the apparent lack of their effectiveness.

Pedestrian Signals and Traffic Operation

Five papers were reviewed that related to the effect of pedestrian signals on traffic operations, of which two were based on studies conducted in the United States, two in England, and one in Australia. The content and coverage of these papers were, however, somewhat varied in nature.

These reviews showed that pedestrian signals are almost always likely to increase pedestrian delay, and in some instances, depending on the vehicular volume and the signal parameters, overall vehicular delay is also likely to increase. Little effort is indicated in the literature regarding equitable allocation of delay among pedestrians and motorists. In particular, the question of how to treat pedestrian delay (relative to motorists who are more comfortably seated within the enclosed environs of the automobile) has received insufficient research attention.

A number of the authors indicated that pedestrians often attempt to get a head start by crossing against a red signal, a maneuver that is associated with higher risk. Thus, the general conclusion to be drawn is that pedestrian delay is likely to increase with the installation of pedestrian signals; and in many cases, vehicular delay is also likely to increase.

Pedestrian Signals and Behavior

The question of behavioral changes is a topic of considerable interest to psychologists and safety researchers. Traffic experts have been interested in this topic primarily because of a possible relation between pedestrian behavior and safety. A total of 10 papers were reviewed on this topic, of which 7 related to experiences in the United States, 1 in England, 1 in Germany, and 1 in Australia. The following conclusions can be drawn:

1. Under low vehicular volume conditions, pedestrians are likely to ignore signal indications, particularly when the clearance interval is longer than the minimum. Pedestrians have a general ten-

dency to accept natural gaps in traffic.

2. The compliance rate for steady WALK signals is higher than that for flashing WALK. Overall, the compliance rate for flashing signals appears to be lower than that for steady signals.

3. Students' propensity toward risk (in crossing streets) increases with age; however, their greater ability to interpret signal indications and to take protective measures in unsafe situations may offset the effect of risk. Accident experiences are lower between about 14 and 60 years of age.

4. The presence of a clearance interval in a pedestrian signal tends to increase compliance rates.

Recommendation for Further Studies

Further research efforts are necessary to provide a more complete answer to the many questions on pedestrian signals.

Create Comprehensive Pedestrian Accident Data Base to Study Effects of Pedestrian Indications

Limited information is reported in the literature regarding actual pedestrian accident data to answer safety-related questions. Some studies have analyzed accident data at individual intersections, but the data base used in these studies is too small to permit the development of any general conclusions. At the level of individual intersections, pedestrian accidents are rare events, notwithstanding that these accidents constitute alarming proportions in the context of all urbanized intersections.

Creation of a larger pedestrian accident data base from different cities that have different types of pedestrian signals and different geometric, operational, and traffic characteristics is considered to be the first critical step in addressing safety-related questions. Next, an analysis should be conducted to extract the effect of various extraneous factors, following appropriate experimental design procedures, so that the net effect of different types of signals can be ascertained.

Establish Relation Between Compliance and Safety

Most researchers have postulated that increased compliance is indicative of improved safety. Although the above hypothesis appears reasonable and logical, further studies are necessary to establish (in quantitative terms) a specific relation between these two factors. Such relations, once developed, may be used effectively by traffic experts and researchers to evaluate more accurately the safety effects of different pedestrian signal modifications and other possible pedestrian safety measures.

Establish Relation Between Pedestrian Behavior and Safety

Several studies have used pedestrian behavior as a measure of safety effectiveness. These studies have used various definitions of unsafe behavior. However, no research has indicated whether any relation exists between pedestrian accidents and pedestrian behavior measures.

Allocate Delay Among Pedestrians and Motorists

The literature review indicates that pedestrian signals will generally result in increased pedestrian delay and often also in increased vehicular delay. If a delay-based signal warrant is to be developed, a prerequisite to this step would be the development of a procedure to allocate delay equitably among pedestrians and motorists. This allocation must also be sensitive to the differential exposure consideration of these two groups (i.e., pedestrians exposed to weather and motorists within the enclosed environment of the automobile).

Define Tolerable Delay

It is not known what constitutes tolerable delay to the average pedestrians (i.e., the maximum waiting time prior to the crossing of the street) before pedestrians might accept unsafe gaps in the main traffic stream. Again, such information will be helpful in the development of a delay-based warrant, particularly at nonsignalized intersections or at midblock crossings.

Develop Optimum Clearance Interval for Pedestrians

The literature review revealed two interesting trends:

1. Clearance intervals generally increase compliance rates and
2. Under low-volume conditions pedestrians are likely to ignore signal indications when clearance intervals are exceedingly long.

Thus, there is a threshold value of clearance interval beyond which pedestrians will accept natural gaps in the traffic stream. If the concept of clearance interval is to be used effectively, one must define this optimum value and develop signal-timing patterns around this optimum value.

Identify Best Signal Indication

Currently, different types of pedestrian signal indications are used in the United States (e.g., word messages and symbols) in different operating modes (e.g., flashing or steady). The literature review did not indicate clearly which combination of pedestrian signals is the most effective in commanding attention of the pedestrians and in increasing their compliance rates. Many studies have indicated a general misunderstanding on the part of pedestrians about the meaning of pedestrian indications. Further studies are needed to answer this question so that local traffic agencies can implement a more uniform signal indication.

Develop Improved Indications to Warn of Potential Conflicts to Pedestrians and Motorists

Some research has been completed in the area of warning of potential conflicts between pedestrians and motorists, but little success has been achieved in developing a clear and effective device to warn pedestrians and motorists of potential conflicts. The flashing WALK indication is currently used in some jurisdictions to warn pedestrians of turning vehicles, but it is not used everywhere. Studies have shown a general misunderstanding of the meaning of the flashing WALK indication.

Possible alternatives to minimize this problem may include more uniformity in signal use, better education of the meaning of the signal indications, and active warning devices for pedestrians, motorists, or others.

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Transportation Control Measure Analysis: Bicycle Facilities

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The Clean Air Act Amendments of 1977 require that areas that have air quality problems examine their transportation system and implement measures to reduce automobile emissions. One of these measures is the improvement of bicycle facilities. The purpose of this paper is to determine the air quality impact and cost-effectiveness of bicycle facilities as a transportation control measure (TCM) for air quality in northeastern Illinois. A case study, based on a survey of the users of commuter bicycle parking at a commuter railroad station and a rapid transit station in a Chicago suburb has been used to determine these impacts. In addition to the air quality benefits and associated costs of current levels of commuter bicycling in Wilmette, some theoretical benefits and costs are calculated by extrapolation from the survey data and application of available ridership information for one of the stations. From the current level of bicycle trips to the station and the theoretical limit of potential trips, a range of possible emission reductions and costs are calculated. Actual potential air quality benefits and costs lie somewhere within this range. Bicycle facilities are implemented locally and bicycling activity varies considerably from one community to another. For these reasons, the impacts of bicycling are best considered at the local scale. For comparison to other TCMs, cost-effectiveness figures can be used. Even fairly expensive bicycle support facilities are found to be very cost effective for air quality improvement in relation to other measures. Each TCM must be evaluated for its socioeconomic as well as its air quality impact. This evaluation is also presented. Bicycle facilities are found to have few socioeconomic drawbacks.

Bicycle facilities are one of the transportation control measures (TCMs) identified by the Clean Air Act Amendments of 1977 for evaluation as a technique to decrease dependence on automobiles and thereby improve air quality. The Clean Air Act of 1970 requires that each TCM be evaluated for its feasibility for use by regions that have air quality problems. The common measure of feasibility used in northeastern Illinois (a six-county area that surrounds and includes Chicago) is the cost per ton of pollutant eliminated by a TCM. This report evaluates the cost-effectiveness for air quality improvement of bicycle facilities for commuters at transit stations. In addition, a socioeconomic impacts assessment required for all TCMs is included.

The analysis of air quality benefits potentially attributable to bicycling depends on estimates of existing and potential bicycling patterns in the region. Bicycle trips neither cause nor decrease air pollution--only when bicycle trips divert trips from other modes, primarily automobiles, can air quality