ITS and Pedestrian Safety: An Evaluation of Automatic Pedestrian Detection at Signalized Intersections

Ronald G. Hughes, Ph.D., Herman Huang, Ph.D., and Charles Zegeer, P.E.

The University of North Carolina Highway Safety Research Center Chapel Hill, NC 27599

April 1999
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ABSTRACT

The present study evaluated the ability of automated pedestrian detection capabilities to provide the means to detect the presence of pedestrians as they approach the curb prior to crossing the street, and then to use that information to ‘call’ the WALK signal without any action required on the part of the pedestrian. The automated detection of pedestrians is not a new concept, having been used successfully in the United Kingdom and elsewhere as part of the PUFFIN (Pedestrian User Friendly Intelligent) and PUSSYCAT (Pedestrian Urban Safety System and Comfort at Traffic Signals) crossing concepts. In the present case, automatic detection was used to augment the use of the standard pedestrian push button, which experience indicates many pedestrians fail to use. Failure to use the pushbutton results in the failure of the system to display the progression of WALK, flashing DON’T WALK, and steady DON’T WALK signals. The objective of the present study was to evaluate whether automated pedestrian detection systems, when used in conjunction with the push button, would result in fewer overall pedestrian / vehicle conflicts and fewer inappropriate crossings (e.g., beginning to cross during DON’T WALK phase). “Before” and “after” video data were collected at intersection locations in Los Angeles, CA (infrared and microwave), Phoenix, AZ (microwave), and Rochester, NY (microwave). The results indicated that the use of automated detection devices in conjunction with the standard pedestrian pushbutton resulted in a reduction in vehicle-pedestrian conflicts as well as a reduction in the number of pedestrians beginning to cross during the DON’T WALK phase. The data reported in this paper were collected as part of a larger study effort which evaluated illuminated pedestrian push buttons, pedestrian countdown timers, and in-pavement flashing crosswalk treatments as well as automated detection applications. Underlying the presumed effectiveness of such treatments is the hypothesis that a more informative pedestrian crossing environment is a safer pedestrian environment.

Note: This research was part of a larger R&D effort conducted by the University of North Carolina Highway Safety Research Center (HSRC) for the Federal Highway Administration (FHWA) under the title, "Pedestrian and Bicyclist Safety," Charles Zegeer, P.E., Principal Investigator.
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INTRODUCTION

A basic underlying concept of the movement toward Intelligent Transportation Systems (ITS) is that the efficiency and safety with which we move persons and goods can be significantly enhanced by making the system more ‘informative,’ both for those who ‘use’ the system as well as for those who ‘operate’ the system. The emphasis on ‘information’ is clearly visible in efforts to develop and deploy Advanced Traveler Information System (ATIS) services which provide real-time route guidance and navigation information to motorists, and to a perhaps lesser extent in efforts to develop and operate Advanced Traffic Management System (ATMS) services. Each of these service areas focuses on the role of information in improving different aspects of motorized travel.

Extending the ITS Concept to Pedestrian Facilities

It has been suggested (see Hughes, 1997) that the concept of ITS might also be applied to the area of non-motorized travel; in particular, to the area of pedestrian behavior. Inasmuch as grade separation between motorized and non-motorized traffic (i.e., pedestrians) is usually not feasible under most conditions where the two modes intersect (such as at intersections and other pedestrian crossing locations), there will continue to be a need to effectively coordinate the joint movement of pedestrians and motor vehicles. The use of illuminated Red/Yellow/Green traffic displays to control the movement of motorized traffic at intersections is well established (MUTCD, 1978). While not perfect in the degree of control achieved, the system serves to effectively maintain the throughput of vehicles with conflicting directions of travel.

Efforts to safely and effectively coordinate the movement of pedestrians at these locations through variations of the traditional WALK, flashing DON’T WALK, and steady DON’T WALK displays, while also described in detail in the MUTCD, are less effective. In part, the reasons seem to be that either the information itself, or its relationship to the behavior of motorized traffic, is not well understood by pedestrians (Zegeer, et al, 1995).

Problems With Traditional System Operation

At many locations, WALK/DON’T WALK information is displayed to the pedestrian only if the pedestrian ‘calls’ the WALK display by pressing a push button usually located on a pole in the vicinity of the curb. Pressing the button, in most cases, produces no direct feedback that the pedestrian’s action has been recognized by the system. Because pressing the button generally does not produce an immediate WALK display, it is not surprising that a large percentage of pedestrians fail to press the button and proceed to cross based upon their perception of the RED/GREEN phase of the signal for parallel and opposing traffic and/or their perception of an acceptable ‘gap’ in oncoming traffic.
Most pedestrians do not recognize that the WALK signal, in most cases, guarantees that a nominal crossing interval (usually equal to a walking speed of about 3.5 to 4 ft/sec) before traffic approaching from the right or left is given a GREEN. In the absence of a WALK display, there is no guarantee that the GREEN time for traffic moving parallel to the path of the pedestrian will be sufficient for the pedestrian to safely reach the other side of the street. Even when the WALK signal is displayed, certain pedestrians (e.g., the physically challenged or elderly) may not be able to reach the other side before the end of the predetermined interval... unless, of course, the system can detect that they are still present in the crosswalk and ‘extend’ the crossing interval until they reach the other side of the street.

**Automating System Detection of the Pedestrian**

In Europe and elsewhere (e.g., Australia) systems have been deployed that automatically recognize the presence of a pedestrian when he/she reaches the curb (see for example: Catchpole, 1995 and 1996; Ekman and Draskoczy, 1992; King, et al., 1994; Van Schagen and Sherborne, 1988). These systems, which variously employ infrared, microwave, or tactile (pressure sensitive) detection technologies for sensing the presence of the pedestrian, have most often been used at un-signalized crossing locations where pedestrian requirements to cross are infrequent and where the chief concern is to otherwise maintain the smooth and continuous flow of motorized vehicles. In such applications the literature indicate that such systems are reliable and effectively accomplish their intended function (Zegeer and Tann, 1996).

**The Need to Evaluate Applications in the US**

These systems have yet to be evaluated in the US; in particular, at signalized intersections where installation and operation would most often be in conjunction with the conventional use of the pedestrian call button. Given the traditional low utilization of the pedestrian call button, the present study sought to determine if the joint use of automated pedestrian detection methods could have a positive effect on pedestrian crossing performance (e.g., fewer pedestrians beginning to cross during a DON’T WALK phase when parallel traffic has a GREEN signal); and, in a case where it was possible to detect the continued presence of a pedestrian in the crosswalk at the end of the predefined crossing interval, whether one could achieve a significant reduction in the percentage of pedestrians still in the crosswalk when opposing traffic was given the GREEN. In addition to determining whether these two aspects of pedestrian performance could be significantly affected by the use of automated detection methods, the study also sought to determine if such methods could result in a reduction in observed pedestrian-vehicle conflicts (a surrogate measure of pedestrian safety).

**Part of a Larger Pedestrian R&D Effort**

This research was conducted at part of a larger study which also addressed the use of conventional and automated detection methodologies to increase the conspicuity and real time information value of pedestrian crosswalk locations both through in-pavement as well as illuminated overhead warning displays. The larger study also addressed the effectiveness of pedestrian countdown displays having the potential for improving the temporal information provided to pedestrians at crossing locations. A final report detailing these findings is currently in preparation.
Taken together, we believe that such treatments are consistent with the goal of the ITS program to address technology applications having the potential for improving the safety and efficiency of important inter-modal relationships (in this case, those between motorized and non-motorized travel at intersecting locations). Such information-driven applications, while at first appearing cost prohibitive, must ultimately be considered against the cost of more traditional ‘physical’ countermeasures such as grade separation as well as the cost associated with continued pedestrian injuries and deaths at intersections.

**METHOD**

**General Concept of System Operation**

The commercially available detection systems used in the present study, whether IR or microwave-based, used pole mounted emitters placed generally about 12 feet above the pavement in the vicinity of the curb adjacent to the crosswalk area. Depending upon the orientation of the emitter, it could be used to either detect the presence of a pedestrian as he/she approached the edge of the curb or the continued presence of a pedestrian still in the crosswalk.

**Treatment/Data Collection Sites**

Data consisted of ‘before-and-after’ periods of sensor operation in three urban locations: Los Angeles, California (infrared and microwave); Rochester, New York (microwave); and Phoenix, Arizona (microwave). For the Los Angeles site, data were collected under three conditions: no automated detector in operation; infrared detector in operation; and microwave detector in operation. Vehicle and pedestrian performances at each location were videotaped for subsequent analysis. These analyses addressed (a) occurrence of vehicle-pedestrian conflicts; (b) pedestrian likelihood of crossing during different signal phases; and (c) pedestrian behaviors while crossing (that is, those who ran, hesitated, aborted, etc.). A brief description of each site is provided in the following section.
Los Angeles, California Site:

**Temple and San Pedro (east side crosswalk).** The Temple and San Pedro site is a ‘T’ intersection. Temple is an east-west street and San Pedro comes from the south to form the ‘T.’ There are marked crosswalks across the east and south legs only; a sign directs pedestrians wishing to cross the west leg to the east leg. The signal controlling the south side crossing is on pedestrian ‘recall.’ Automated pedestrian detectors were added to the eastside crosswalk where pushbuttons were already present. On both the northeast and southeast ‘corners,’ one detector picked up pedestrians who stepped into the detection zone on the sidewalk (waiting to cross the street) while a second detector picked up pedestrians who were still in the crosswalk.

If a pedestrian was detected as still being in the crosswalk, the system was programmed to extend the crossing time by 0.2 second increments to a maximum of six additional seconds. The extended crossing time corresponded to a walking time of 3 ft/sec compared with the customary 4 ft/sec. During the extended crossing interval, the steady DON’T WALK display was presented to pedestrians and the onset of the GREEN signal for opposing motorists was delayed.

Rochester, New York Sites:

**Crittenden and Latimore (north side crosswalk).** Lattimore is a north-south road, and Crittenden is an east-west road. The west leg of this intersection is an entrance to a large parking lot. Both the north side and the south side crosswalks were controlled by pushbuttons. Each pushbutton controlled both (i.e., northside and southside) crosswalks. The signal controlling the eastside crosswalk was on pedestrian recall. Unlike the other three crosswalks, the westside crosswalk was a ladder design, and was not controlled by a pedestrian signal. The north side crosswalk was the treatment site. It connected the parking lot to the University of Rochester medical complex. The south side crosswalk connects two parking lots.
State and Corinthian (north side crosswalk). This intersection is in downtown Rochester. State is a north-south arterial, whereas Corinthian is a very short east-west street that forms a T-intersection to the west. The east end of Corinthian is a municipal parking garage. The north side crosswalk is controlled by a pushbutton. This was no pedestrian signal controlling the eastside crosswalk. The south leg did not have a marked crosswalk. State always had the green light unless there was a vehicle on Corinthian or unless a pedestrian has pushed the button.

Phoenix, Arizona Site:

Central at Earll. Central Avenue is a major arterial with seven lanes and an ADT of more than 38,000. Earll Drive is a main driveway to Park Central Mall (west leg) which aligns with a local street on the east side of the intersection. The vehicle traffic on Earl Drive is intermittent and the number of pedestrians crossing Central Avenue varies throughout the day. At times pedestrian crossings may be quite high. Since traffic volumes on Central Avenue is high for most of the day, fixed-time operation (which would provide a pedestrian WALK interval on every cycle, including times when pedestrians are not present) could cause substantial congestion on Central Avenue, and is not an acceptable form of signal operation.
RESULTS

Effect on Pedestrian Behavior

Figure 6 shows the percentage of pedestrians who began to cross during the DON’T WALK phase as a function of whether the pushbutton alone or the push button plus automated detection capabilities were in effect.

At the Temple and San Pedro site in LA where both IR and microwave approaches were evaluated, the data show that when used in conjunction with the push button both approaches resulted in a significant reduction in the percentage of pedestrians beginning to cross during the DON’T WALK phase of the signal ($\chi^2=6.019$, df=1, $p=.014$). IR and microwave detection capabilities, while each produced results that were significantly different from the push button only condition ($\chi^2=6.586$, df=2, $p=0.037$), did not differ in terms of the level of effectiveness associated with each ($\chi^2=0.867$, df=1, p=0.352).

In Rochester, at the Crittenden and Latimore site, use of the microwave-based device in conjunction with the push button also resulted in a significant reduction in the number of pedestrians beginning to cross during the DON’T WALK phase ($\chi^2=43.935$, df=1, $p=.001$). The same effect was achieved at the Central and Earl site in Phoenix ($\chi^2=11.317$, df=1, $p=.001$). A significant effect was not, however, achieved with the microwave detection capability installed in Rochester at State and Corinthian ($\chi^2=.036$, df=1, $p=.849$). This could be largely due to the result of the small sample sizes of pedestrians observed during the data collection period.

Thus, significant effects in the direction of improved control over pedestrian performance were achieved at three of the four test sites. The magnitude of these effects, while not large, is consistent with that obtained elsewhere (see Catchpole, et al (1996)). At the San Pedro site in LA where a comparison of IR and microwave technologies was possible, effects produced by the two approaches were not statistically different.

With respect to use of the additional sensor to extend the crossing time for pedestrians still in the crosswalk, the present data show the following:
(1) Without any form of automatic pedestrian detection or extension, 47 percent of pedestrians at the Temple and San Pedro site finished crossing during the steady DON’T WALK phase of the signal while parallel traffic still had a GREEN. With the extension capability operational, there was a significant increase (from 47 to 53 percent) in pedestrians who finished during the steady DON’T WALK while parallel traffic still had a GREEN ($\chi^2=5.496$, df=1, $p=.019$). . . even though fewer pedestrians began to cross during the same steady DON’T WALK condition.

(2) The addition of the extension capability also resulted in a significant reduction (from 16 percent to 7 percent) the percentage of pedestrians who finished crossing during a steady DON’T WALK display after the signal for oncoming traffic had turned to GREEN ($\chi^2=42.017$, df=1, $p=.001$).

Taken together, these data indicate that the extension capability was, in fact, serving to increase protected time for pedestrians, allowing more time to complete crossing during the (still protected) steady DON’T WALK (parallel traffic GREEN) while reducing the percentage of pedestrians still in the street during the unprotected DON’T WALK (oncoming traffic GREEN).

Pedestrian Perception of System Status

The Temple and San Pedro site in LA provides some interesting data for that portion of time when, for study purposes, the pushbutton was taped over (i.e, not operational). The intent was to collect data under conditions where only the automated detection capability (i.e, without pushbutton) was in effect. This analysis was made possible at the LA site since city officials decided initially to tape over the pedestrian push button when the IR detectors were first installed. The data in Figure 7 shows that when the button was taped over (but the IR detector was still operational) pedestrians were almost 5 times more likely to begin crossing during the displayed DON’T WALK phase as when the button and IR detector were both present and functioning. Somehow, the perception that the pushbutton component of the system was not functional produced a perception on the part of pedestrians that information presented by the system was unreliable (remember that IR detection still resulted in appropriate WALK, flashing DON’T WALK, and steady DON’T WALK displays). These results suggest that when automated pedestrian detectors are used, it may still be important to provide push button devices.
and/or to provide pedestrians with feedback that automated detection systems are in place and working correctly (the same rationale associated with the proposed use of illuminated pushbuttons).

The Effects of Automated Detection on Pedestrian-Vehicle Conflicts

Conflict data were available from the Temple and San Pedro site in Los Angeles and from the two Rochester sites (see Figure 8). For the LA site at Temple and San Pedro, use of automatic pedestrian detection capabilities in conjunction with the conventional push button resulted in a significant reduction in vehicle-pedestrian conflicts ($\chi^2 = 33.533$, df=1, $p = .001$). There were no significant differences in terms of whether the type of detection capability employed was IR or microwave ($\chi^2 = .918$, df=1, $p = .338$). Similar effects were obtained with use of microwave detection capabilities at Crittenden and Latimore in Rochester ($\chi^2 = 17.653$, df=1, $p = .001$) and at State and Corinthian ($\chi^2 = 16.311$, df=1, $p = .001$) in Rochester. Conflict data from the Phoenix site could not be analyzed due to video limitations associated with data collection at the site. In terms of observed pedestrian behaviors (e.g., hesitating, running, etc.), the most typical pedestrian behavior was running which occurred roughly between 10 and 15 percent of the time at all sites, regardless of whether or not the pushbutton was augmented with automatic detection capabilities. Running can be a response to a number of things: seeing the flashing or steady DON’T WALK phase; to seeing the light for parallel traffic change to yellow; to experiencing the approach of traffic from the left or right; or simply to get out of the path of a turning vehicle. In the case of the Temple and San Pedro site in Los Angeles, taping over the pushbutton (automated detection still operable) resulted in an increase in observed running from 7 per cent to 17 percent of pedestrians. This parallels the significant increase in conflicts during this same condition (see above).

![Figure 8](image.png)

**Figure 8.** Percentage of Pedestrians Experiencing Conflicts With Motor Vehicles

In the case of the Temple and San Pedro site in Los Angeles, taping over the pushbutton (automated detection still operable) resulted in an increase in observed running from 7 per cent to 17 percent of pedestrians. This parallels the significant increase in conflicts during this same condition (see above).

Figure 9 shows the extent to which the relationship between conflicts and the likelihood of pedestrians crossing during the DON’T WALK phase can be described by a simple linear relationship. A linear relationship accounts, in the present case, for only about 20 percent of the variance ($R^2 = .20$). Note that the y-intercept of the function would lead one to predict that there about 10 percent of all pedestrians would still encounter some form of conflict even if the
percentage of pedestrians beginning to cross during the DON’T WALK phase were reduced to zero.

**Figure 9.** Pedestrian-Vehicle Conflicts as a Function of the Percentage of Pedestrians Crossing During the Steady DON’T WALK Phase.

Logarithmic and exponential ‘fits’ were found to offer no advantage over the simple linear function. While it was possible, for example, to account for almost twice the variance with a fourth order polynomial, the process that might be responsible for producing such a complex relationship is not at all clear. More precise clarification of these relationships lies beyond the limited data provided from observations of these four sites. Suffice it to say that as more pedestrians begin to cross during the DON’T WALK phase, more will still be in the street when opposing traffic begins to move, and therefore more conflicts will occur. While conflicts from opposing traffic could be minimized by the system delaying the green for opposing traffic, conflicts from turning vehicles would still be present.

**Accuracy of Microwave Sensors**

The discussion above dealt with the effects of the automatic detectors on pedestrian behavior. A separate study, conducted by the Phoenix, Arizona Traffic Engineering Department, was conducted to address sensor detection zones. Prior to full activation of the detectors, a red light was attached to the signal pole to illuminate when the sensor detector a pedestrian. This test was used to determine the number of false alarms as well as missed pedestrian calls at the Central and Earll test site.

The initial testing revealed problems with the sensors on occasion falsely detecting slow moving, right turn vehicles next to the pedestrian detection zone. Operationally, this would result in more WALK displays than necessary and could reduce GREEN time to motor vehicles crossing the crosswalk of intent. Based on recommendations of the manufacturer, rotation of the system’s antenna resulted in a reduction in false alarms. False detections also occurred in conjunction with a heavy rain during the test period, which resulted in the sensor giving false calls on each cycle.
There were also a few missed calls during the testing period, but these were much fewer in number than the number of false alarms. Pedestrians ‘missed’ by the automatic detection system could, of course, still call the WALK signal if the button was pressed.

After various adjustments were made to the sensors, they were fully activated with the pedestrian signal equipment for full evaluation, as discussed previously. In general, while the sensors did not perform correctly in all cases, their effect upon pedestrian behavior was in the right direction. Experience however indicates that further fine tuning of the equipment could result in additional benefits to pedestrians while minimizing adverse effects on motor vehicle flow.

**SUMMARY AND CONCLUSIONS**

The data provide evidence that the use of capabilities to automatically detect presence of pedestrians at crossing points can improve the performance obtained with the conventional pedestrian push button alone. The data shows that improvements can be expected in terms of

- A decrease in the likelihood that pedestrians will begin crossing during the steady DON’T WALK phase of the signal, the consequence of which is not having sufficient time to clear the crosswalk before encountering opposing traffic.

Figure 10 shows that, in the present study, the addition of automated pedestrian detection capabilities to sites with existing pedestrian push buttons resulted in a 24 percent increase in the number of pedestrians who began to cross during the WALK phase of the signal. This was accompanied by an 81 percent decrease, on the average, in the number of pedestrians who began to cross during the steady DON’T WALK phase. The number of sites upon which these results are based is small, and as the data have shown, pedestrian performance can vary widely across sites. One should therefore be cautious in terms of the exact level of improvement to be expected at any given site.
A decrease in the number of conflicts experienced by pedestrians while crossing.

Figure 11 shows that all types of conflicts recorded in the present study were reduced by the addition of automatic detection capabilities to sites using conventional pedestrian push buttons. Conflicts encountered by pedestrians during the first half of their crossing (TH-1) were reduced by 89 percent; conflicts during the second half by 42 percent. Conflicts associated with right turning vehicles (RT) were reduced by 40 percent. ‘Other’ types of conflicts were reduced by 76 percent.

![Bar chart showing percent change in pedestrian-vehicle conflicts](image)

**Figure 11.** Percent Change in Pedestrian-Vehicle Conflicts Associated with the Addition of Automatic Pedestrian Capabilities Compared to the Same Sites Using Conventional Pedestrian Pushbuttons

Automatic pedestrian detection capabilities seem to derive their effectiveness *not* from their relationship to the pedestrian information that is displayed, per se, (since the information is identical to that provided when the push button is pressed), but rather in their role in increasing the likelihood that the presence of a pedestrian will be reliably detected by the system and therefore receive appropriate information.

System awareness of the pedestrian (either as a result of the push button being pressed or via automatic detection) is important in that it ensures that at least a minimum interval will be provided for the pedestrian to cross. The pedestrian who begins to cross without using the push button to ‘call’ the system has no way of knowing the duration of the green time for parallel traffic, and therefore can risk crossing under conditions where there is less than adequate time to reach the other side of the street.

Neither the presence of a push button nor a push button used in conjunction with automatic detection can, however, ensure complete control over pedestrian crossing behavior. None of the test sites in the present study were characterized by a complete absence of unsafe, or inappropriate, pedestrian behavior. However, irrespective of local or site differences in the degree of signal control over pedestrian crossing behavior, the present data clearly show that use of automatic detection can result in positive changes in pedestrian behavior during critical portions of the crossing sequence, and that such changes are associated with a measurable decrease in the risk associated with pedestrian/motor vehicle conflicts.
Even with current engineering limitations, it appears that applications of automated pedestrian detection capabilities will become more widespread in the US over the next few years both at signalized as well as non-signalized (e.g., mid-block) locations. It is important that these installations be carefully monitored over time in order to (a) more precisely define the operational parameters under which automated pedestrian detection is ‘warranted,’ and (b) to quantify the extent to which reduced vehicle-pedestrian conflicts associated with automated pedestrian detection and other ITS pedestrian-centered applications translate into measurable reductions in pedestrian injuries and fatalities.

REFERENCES


