

ENGINEERING METHODS FOR DESIGNING SAFE PEDESTRIAN FACILITIES

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Abstract

In the recent years there has been an interest in promoting pedestrian travel as an alternative to the use of automobile. In that respect transportation engineers should consider pedestrian needs and design facilities that enhance safety and efficiency for all users. However, this task is a difficult one since satisfaction of pedestrian needs often presents a conflict of interest with the needs of motorized users.

A variety of traditional and innovative approaches exist to assist engineers design facilities that accommodate safety needs of pedestrian users. The paper undergoes an extensive review of the literature and summarizes a variety of new approaches that are used to improve design of pedestrian facilities. The paper describes the concept and applicability of each approach, and evaluates its effectiveness based on results reported in the literature.

The review indicates that while each approach has certain benefits to offer, concurrent implementation of a variety of techniques is often required to heighten motorists' awareness of pedestrian presence and increase pedestrian safety.

1. Introduction

During the 1990s, Congress spearheaded a movement towards a transportation system that favors people and goods over motor vehicles with the passage of the Intermodal Surface Transportation Efficiency Act (1991) and the Transportation Equity Act for the 21st Century (1998). The call for more walkable, liveable, and accessible communities, has helped bicycling and walking emerge as an "indicator species" for the health and well-being of a community. People want to live and work in places where they can safely and conveniently walk and/or bicycle and not always have to deal with worsening traffic congestion, road rage and the fight for a parking space (1)

As the interest in walking as a transportation alternative increases so does the need for providing a safe pedestrian environment that encourages pedestrian activities while maintains pedestrian safety. Proper planning and designing practices that ensure safety and comfort for pedestrian users are equally important when building new roads and communities as well as when retrofitting the built environment. The challenge for transportation planners, highway engineers and pedestrian user groups is to balance their competing interest in a limited amount of right-of-way, and to develop a transportation infrastructure that provides access for all, a real choice of modes, and safety in equal measure for each mode of travel.

2. Literature Review

A wide range of available treatments exist that can be applied to accommodate safety needs of pedestrian users. In the recent years many design guides have been developed at the local and national level that offer guidance on recommended practices (2), (3).

For example the Florida DOT (Florida DOT, Florida Pedestrian Planning and Design Handbook, 1999) and New Jersey DOT have integrated bicycle and pedestrian facility design information into their standard highway design manuals. ITE (4) and AASHTO (5) have developed comprehensive guides for development of pedestrian facilities. A great, user-friendly guide is developed by the FHWA and available online at (6). This guide is developed in a matrix format and provides a list of common pedestrian safety problems and countermeasures to reduce them.

The review of the literature clearly shows that there are a number of engineering-related options that can provide improved facility designs for pedestrian convenience and safety. Some of these relate to the design of the roadway, others focus on the pedestrian facilities, and some are specific to intersections that serve mixed traffic. The next section provides a brief summary of traditional engineering treatments for improved pedestrian safety whereas selected innovative applications of Intelligent Transportation Systems technologies follow.

3. Traditional Engineering Treatments for Pedestrian Safety

3.1 Design and Placement of Sidewalks (7)

No single design feature can ensure that a streetscape will be attractive to pedestrians. Rather, the best places for walking combine many design elements to create streets that "feel right" to people on foot. Street trees, separation from traffic, seating areas, pavement design, lighting, and many other factors should be considered in locations where pedestrian travel is accommodated and encouraged.

All urban sidewalks require the following basic ingredients for success: adequate width of travel lanes, a buffer from the travel lane, curbing, minimum width, gentle cross-slope (2 percent or less), a buffer to private properties, adequate sight distances around corners and at driveways, shy distances to walls and other structures, a clear path of travel free of street furniture, continuity, a well-maintained condition, ramps at corners, and flat areas across driveways. Sidewalks also require sufficient storage capacity at corners so that the predicted volume of pedestrians can gain access to and depart from signalized intersections in an orderly and efficient manner. AASHTO provides detailed information on design standards that need to be met in order to provide desirable walking conditions for pedestrian travel (5).

Sidewalks are recommended on both sides of all urban arterial, collector, and most local roadways. Although local codes vary, AASHTO and other national publications insist that separation of the pedestrian from motorized traffic is an essential design feature of a safe and functional roadway.

The AASHTO Policy on Geometric Design of Highways and Streets (Greenbook) (5) does not fully address the issue of sidewalk placement, in lightly developed areas, however, it does recommend that rights-of-way be preserved on all arterial and collector roadways. Although AASHTO and many other organizations suggest that some short sections of local streets can have sidewalks on one side only, the designer should consider that single-side sidewalks can create unwanted motorist/pedestrian conflicts.

3.2 Pedestrian Signing and Pavement Markings

Traffic engineers use a wide variety of road signs and pavement markings. Some are used to alert motorists to pedestrian activity and to direct pedestrians to defined crossings. Problems are created, however, when pedestrians assume that signs and paint will protect them from cars. Drivers, on the other hand, often ignore pedestrian signs and markings because they seldom see many pedestrians. As a result, signs and paint may lull pedestrians into a false sense of security.

The Manual on Uniform Traffic Control Devices (MUTCD) (8) outlines guidelines governing signs and pavement markings. At the same time, it does not prohibit creative regulatory design. The MUTCD does not define criteria for crosswalk location or striping options. Much is left to engineering judgment. As a result, there is leeway in adapting guidelines to specific signing and marking policy needs.

In the recent years some innovative applications were tested with success, include the pedestrian safety cones introduced in New York, NY, overhead pedestrian regulatory signs implemented in Tucson, AR, and overhead crosswalk signs such as those used in Seattle, WA, and Clearwater, FL. Figures 1 to 3 provide illustrations of such applications.

FHWA (10) carried out an assessment study for the New York pedestrian safety cones, Tucson overhead signs, and overhead crosswalk signs in Seattle. The study results confirmed that pedestrian safety cones could improve conditions for pedestrians by increasing the percentage of motorists yielding to them (from 69.8% to 81.2% after the cone installation). The study also concluded that locations where overhead crosswalk signs were available showed an increase in



Figure 1: New York Pedestrian Safety Cone Application (9)



Figure 2: Tucson Overhead Pedestrian Regulatory Sign (9)



Figure 3: Illuminated Overhead Crosswalk Sign in Clearwater, Florida (9)

the percentage of pedestrians for whom motorists yield (from 45.5% before to 52.1% after the sign installation) that was significant at the 0.001 level. Moreover, fewer pedestrians ran, aborted, or hesitated after the overhead crosswalk sign was installed in Seattle (43.1% after versus 58.2% before). Another study that assessed illuminated overhead pedestrian crosswalk signs in Florida reveal that daytime drivers were 30 to 40 percent more likely to yield to pedestrians at the locations with the devices, compared with locations without the

devices, while nighttime drivers at the experimental locations were only 8 percent more likely to yield (11).

Overall, evaluation studies confirm that positive reinforcement is beneficial to pedestrian safety and can be accomplished by the use of pedestrian signs and pavement markings that are easy to recognize and properly placed.

3.3 Pedestrian Accommodations at Intersections

Walkways provide mobility along a linear path. But eventually, people need to cross roads and streets at intersections. These intersections, where the paths of people and vehicles come together, can be the most challenging part of negotiating a pedestrian network. If pedestrians cannot cross the street safely, then mobility is severely limited, access is denied, and walking as a mode of travel is discouraged (7).

Several design features are critical in order to provide for pedestrian access at intersections. These include crosswalk design and placement, curb bulbs and curb radii, pedestrian refuge islands, and signal placement and timing. Much research has been done on these topics in the past, and several design manuals provide more detail, including the *Manual on Uniform Traffic Control Devices* (8), AASHTO's Policy on the Geometric Design of Highways and Streets (5), and ITE's Design and Safety of Pedestrian Facilities (4) among others.

The latter summarizes important intersection issues for consideration as follows (4):

- 1. Improved pedestrian conspicuity.**

Ways to alert motorists to the possible presence of pedestrian activity at intersections include providing painted crosswalks in the roadway, moving pedestrians out from behind parked cars through the use of bulb-outs, and improving both horizontal and vertical sight distances through the removal of extraneous curbside clutter such as newspaper boxes, redundant utility poles, or overgrown vegetation. The use of traffic calming devices such as raised intersections tells drivers that the area is not designed for rapid through movement, but rather it is an area where pedestrians can be expected. Drivers must exercise caution when approaching raised intersections and be ready to yield right-of-way to pedestrians. Another way to slow drivers is to design right-turn slip lanes with exit angles between 50 and 60 degrees.

- 2. Predictability of pedestrian actions and movement.**

Pedestrian movement can be controlled and made more routine and visible through the use of crosswalks and signalization.

- 3. Distance and time that pedestrians have to cross a roadway.**

Both the distance and time it takes pedestrians to cross a street can be shortened through the use of curb bulbs, medians, and refuges.

- 4. Ease of movement from walkway to street level and vice versa.**

Curb ramps facilitate the transition from walkways to streets. Raised intersections can make it easier to meet the Americans With Disabilities Act (ADA) requirements as a crosswalk becomes a natural extension of a walkway and the need for curb ramps is eliminated.

4. Innovative Technology Applications for Improved Pedestrian Safety

To date, the development and application of Intelligent Transportation System (ITS) technologies has primarily focused on motor vehicle safety and mobility. However, recent developments in hardware and other technologies offer the potential of improving pedestrian

safety and access by addressing specific problems associated with crossing the street. Properly installed and operated, the application of these devices can enhance the safety of traveling environment (Figure 4).

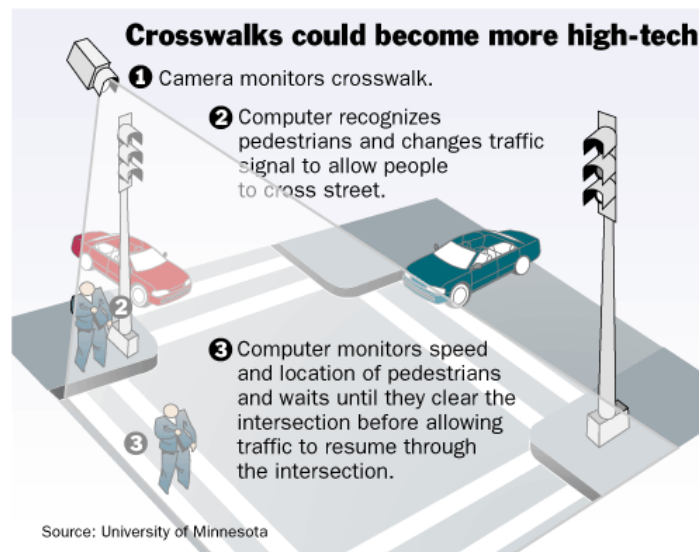


Figure 4: High-Tech Crosswalk

The literature indicates that ITS technologies can address many problems currently associated with pedestrian safety (12). Some of these technologies can increase motorist awareness of pedestrian presence, others can provide feedback to pedestrians and assist them in making the right decisions, and some hold promise toward assisting visually impaired and other disadvantaged pedestrian users. Selected ITS applications are presented next followed by a summary of technology assessment.

4.1 Application Introduction

4.1.1 Pedestrian Detection

The traditional detection method of pedestrian presence is the pedestrian-activated push button. Previous studies (13) showed that only a very low percentage of pedestrians use the push button. Among the reasons cited for this fact are that the push button is hard to find, poorly located, not expected, or does not provide direct immediate feedback to pedestrian for pushing. Given the ineffectiveness of pedestrian push buttons it appears beneficial to introduce warning devices activated without having to rely on the pedestrian to push a button.

A better approach to triggering the device may be passive detection of the pedestrian. Types of sensors being used include infrared, ultrasonic, microwave radar, video imaging, or piezometric sensors. These sensors provide the means to automatically detect the presence of pedestrians in either the targeted curbside area and/or while moving in a designated crosswalk area. When used at the curbside area, they may either replace or augment the standard push button used to activate the pedestrian call feature. When used to detect pedestrians in the crosswalk, the function of the sensors is to detect the presence of individuals requiring additional time to cross, and accordingly extend the clearance interval and provide more time to cross (Figure 5).

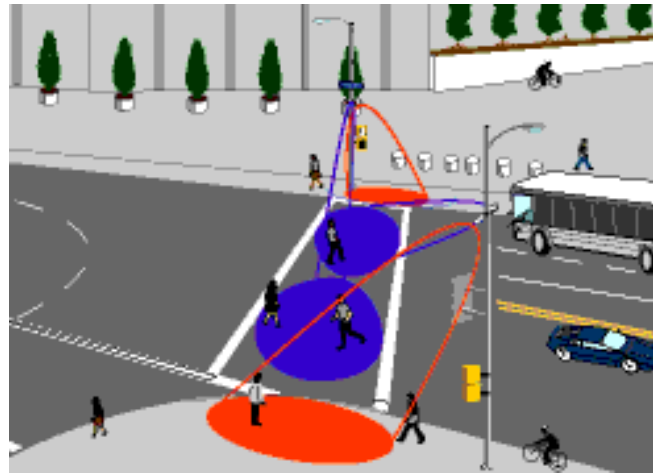


Figure 5: An Automatic Detection System

4.1.2 Increased Motorist Awareness

There are a lot of ITS applications that can be used to increase motorist awareness of pedestrian presence. Some sensor-based solutions, for example, let vehicles "look ahead" and detect pedestrians in their surroundings. These include passive, video-based approaches and approaches involving active sensors (radar and laser range finders) that detect pedestrians and inform drivers of pedestrian presence using in-vehicle displays (14).

Another technology that can be used to inform motorists of pedestrian presence is the in-pavement flashing lights. In-pavement lights are being used at crosswalks to alert motorists to the presence of a pedestrian crossing or preparing to cross the street. The amber lights are embedded in the pavement on both sides of the crosswalk and oriented to face oncoming traffic. When the pedestrian activates the system, either by using a push-button or through detection from an automated device, the lights begin to flash at a constant rate, warning the motorist that a pedestrian is in the vicinity of the crosswalk ahead.

The amber LED lights flash in unison at a rate designed for maximum motorist recognition and are visible during the daylight as well as at night. The flashing lights are only activated when a pedestrian wants to cross and are automatically shut off after a set period of time, i.e., the time



Figure 6: Illustration of a Crosswalk with In – Pavement Flashing Lights

required for a pedestrian to safely cross the street. If installed in conjunction with the means to detect the presence of pedestrians while in the crosswalk, the crossing interval can be extended, in which case the lights would continue to flash and allow slower pedestrians to safely cross. One well-known example of such a system is the *LightGuard System*, where the flashing lights are activated by passive pedestrian detectors.

4.1.3 Feedback to the Crossing Pedestrian

Examples of technologies that can provide feedback to crossing pedestrians include the countdown signal and the animated eyes applications.

4.1.3.a Countdown Signal

Prior research has shown that pedestrians do not fully understand the meanings associated with the three phases of a pedestrian signal (i.e., WALK, flashing DONT WALK, and steady DONT WALK). The phase that is most misunderstood is the flashing DONT WALK. (15) Many people think the flashing red light means "speed up" when actually the flashing DONT WALK phase is a clearance interval and is intended to provide pedestrians with the message that they should complete their crossing if they are in the street and do not to start crossing if they are not in the street. This lack of understanding results in the need to either better educate pedestrians as to the meaning of the messages or to provide additional information that can be used by pedestrians to make better decisions regarding when to cross the street. The countdown signal is a device that displays such additional information for pedestrians.

Countdown signals are used in conjunction with conventional pedestrian signals to provide information to the pedestrian regarding the amount of time remaining to safely cross the street. It is hypothesized that pedestrians will use this information to make better decisions about when to enter the crosswalk. Depending on user preference, the countdown timer starts either when the WALK or Walking Person indication appears or when the flashing DONT WALK or Hand indication appears. The timer continues counting down through the flashing DONT WALK (Hand) clearance interval. When the steady DONT WALK or Hand appears, the countdown signal will be at zero. (15)



Figure 7: Pair Looks of a Countdown Signal

4.1.3.b Animated Eyes

Another problem for crossing pedestrians appears to be a lack of understanding or awareness that turning vehicles may be crossing their paths during the WALK phase of the pedestrian signal. While the drivers of these vehicles are obligated to yield right-of-way to the pedestrians, they sometimes do not. The result may be a serious conflict or crash.

Animated eyes are intended for use at pedestrian crosswalks as an alternative to conventional pedestrian signals. Animated eyes displays are expected to encourage pedestrians to look for turning vehicles traveling on an intersecting path by including a prompt as part of the pedestrian signal. The prompt is a pair of animated eyes that scan from side to side at the start of the WALK indication. Depending on user preference, the animated eyes can be illuminated separately from the standard pedestrian symbol at the beginning of the WALK phase or illuminated concurrently with the standard symbol. The animated eyes can also be illuminated repeatedly at regular intervals throughout the WALK phase to continually inform them to watch for turning vehicles (9).

The animated eyes display uses a light-emitting-diode (LED) pedestrian signal head and adds animated eyes that scan from side to side. The device uses narrow (8 degree) field of view LEDs on a black background. The display is highly visible to pedestrians while restricting signal visibility to motorists (15).



Figure 8: A Pedestrian Signal with Animated Eyes

4.2 Application Evaluation

4.2.1 Pedestrian Detection Assessment

In Finland, there are several installations of pedestrian detection systems in the city of Helsinki where radar detectors are used to detect pedestrians approaching a pedestrian crossing (16). Radar detection is especially used when there is a high probability that a pedestrian approaching the crossing also will cross the street. A few tests have also been done in Sweden and Norway to extend the green by using radar detectors. One problem noticed is that cars standing close to the pedestrian crossing can be detected as pedestrians. The extension of the green time does not solve any real safety problem. Detecting pedestrians to prevent pedestrians from walking against red signal is more important from a safety point of view. (16)

In a joint European study (16), trials with microwave detectors to trigger the traffic signal were carried out. In one trial in a small town (Växjö), detectors were mounted to detect all approaching pedestrians. The detectors were connected to the pushbuttons, thereby having the same effect as pushing the button.

The result showed a significant reduction of red walking among the pedestrians, simply because it was more often green when the pedestrians arrived at the pedestrian crossing. The effect was especially strong for pedestrians crossing the minor road. The effects on vehicle traffic were negligible since the traffic signal program was very vehicle-friendly to start with. The false detection of pedestrians approaching the crossing without any attempt to cross was not found to be a major issue and was comparable to that of pedestrians pushing the button without waiting for the green light either by walking against red or by crossing the other street instead.

In the US, a study (17) was carried out to evaluate automated pedestrian detection systems installed at sites in Los Angeles, CA (infrared and microwave); Phoenix, AZ (microwave); and Rochester, NY (microwave). At the Los Angeles site, a second set of sensors was used to detect pedestrians who were crossing in the crosswalk.

The analysis found that, in the presence of automated pedestrian detection, the number of pedestrian who began to cross during the steady Don't Walk signal were 81 percent lower than before. Moreover, the addition of automatic detectors to sites using conventional pedestrian push buttons reduced vehicle-pedestrian conflicts. Conflicts encountered by pedestrians during the first half of their crossing were reduced by 89 percent, and conflicts during the second half by 42 percent. Conflicts associated with right-turning vehicles were reduced by 40 percent. "Other" types of conflicts were reduced by 76 percent.

4.2.2 In – Pavement Flashing Lights Assessment

In 1996, the California Traffic Control Devices Committee (CTCDC) endorsed the testing (18) of the system in California cities in order to determine if the device should be sent on to the California State Department of Transportation for standardization. The tests were conducted in the Cities of Fort Bragg, Lafayette, Petaluma, Willits, Orinda, California and Kirkland, Washington. Additional evaluation was conducted at one of the original Santa Rosa test sites two years following the initial installation of the device.

The findings confirm that flashing amber lights embedded in the pavement at uncontrolled crosswalks have a positive effect in enhancing a driver's awareness of crosswalks especially under adverse weather conditions such as darkness, fog, and rain. The warning system seems to be particularly effective at locations where there is at least a moderate flow of pedestrians (100 pedestrian crossing per day). At speeds less than 35 mph, drivers seem to be able to respond properly if at least 400 feet of sight distance is provided to the warning

system. At speeds greater than 40 mph, drivers seem to have difficulty stopping safely if less than 600 feet of sight distance is available prior to the warning lights.

4.2.3.a Countdown Pedestrian Signals Assessment

The University of North Carolina Highway Safety Research Center conducted the evaluation of the effects of pedestrian countdown signals in Lake Buena Vista, FL. (19) The results revealed that the countdown signals had both positive and negative effects on pedestrian behavior at the treatment sites, compared to the matched control sites. A potential drawback of a countdown signal is that some pedestrians, who would otherwise wait for the next Walk signal, may be encouraged to start crossing on the flashing Don't Walk, with insufficient crossing time.

Based on these results and those of other studies, countdown signals were not recommended for use at standard intersections in Florida. Countdown signals may result in more pedestrian signal violations among some age groups. For example, teenage and young adult males (such as near high schools and universities) may try to "beat the light" after seeing that they still have several seconds to cross. Countdowns may be more promising at intersections that are frequented by an older adult population, by virtue of the added information about the time available for crossing.

Another evaluation of countdown pedestrian signals was conducted by Mn/DOT and representatives from city and county agencies. The analysis revealed that the pedestrian countdown indicators, used in conjunction with the international symbols, increased the percent of successful crossings from 67 percent to 75 percent. The countdown indicators showed the greatest impact among the elderly, whose percentage of successful crossings rose from 57 percent to 68 percent, and among teens, whose percentage of successful crossings jumped from 53 percent to 73 percent.

4.2.3.b Animated Eyes Assessment

In 1999, Ron Van Houten et. al. (20) tested an experimental animated light-emitting diode (LED) pedestrian signal head that included two eyes with eyeballs that scanned left and right. The analysis showed that the device significantly increased pedestrians' observing behavior and reduced pedestrian-motor vehicle conflicts at two signalized intersections. Benefits were sustained over six months, suggesting they were not merely novelty effects. Both intersections examined in this research consisted of roads carrying two-way traffic.

In the following year, Ron Van Houten and Malenfant (20) conducted another series of experiments to test the generality of their previous finding by examining the efficacy of the animated eyes symbol with a variety of typical intersection geometries, and timing parameters. The experiments included: a) Multi site conflict study; b) Analysis of directional prompting and repeated prompting; and c) Presenting the "Eyes" during the entire WALK interval.

In the first experiment the conflicts were examined before and after the animated eyes were introduced at two intersections with one way traffic on both streets, four intersections with two way traffic on both streets, and two intersections with one way traffic on one street and two way traffic on the other. Conflicts were reduced at crosswalks on all eight streets with significant reductions on 7 of the 8 streets.

The second experiment examined whether it was better to have the eyes look in both directions, eyes scanning back and forth with equal dwell times in each direction, or only in the direction of the threat, unequal dwell times with the eyes looking longer in the direction of the threat, at crosswalks on one-way streets.

The results of this study showed that looking one way was no more effective than looking both ways. The effect of varying the percentage of the time that the eyes message was repeated during the WALK interval on looking behavior and conflicts was examined in the second, and third experiments. The results of this study also showed that having the eyes on during the entire WALK interval was no more effective than having the eyes alternately on for 3.5 seconds and off for 3.5 seconds, but having the eyes alternately on for 3.5 seconds and off for 7 seconds was somewhat less effective.

5. Conclusions

There is an increased emphasis on planning and design of facilities that accommodate pedestrian needs as a result of national legislation and grassroots support in local communities. In this context the role of engineers and planners is to develop and refine the physical facilities and space -roadways, sidewalks, crosswalks, lights, and traffic control devices- that help safeguard pedestrians. Additional attention should be given to pedestrian users with special needs (such as children and the elderly) that are a more vulnerable and significant segment of pedestrian population. Many traditional and innovative techniques exist that can assist engineers to design facilities that accommodate safety needs of pedestrian users. The corner stones of a successful, efficient, and well-balanced transportation system are engineering judgment, and accommodation of mobility and accessibility needs of all users.

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