Safe Accommodation of Pedestrians at Intersections

MARTIN T. PIETRUCHA AND KENNETH S. OPIELA

For years there has been an independent approach to the design of highways and streets to accommodate vehicle and pedestrian movements. The highway and street design process in the AASHTO geometric design policy is examined from a pedestrian design perspective to determine the adequacy of highway design standards in considering the pedestrian, the appropriateness of current design treatments, the compatibility of pedestrian facility designs and highway facility designs, and the effectiveness of the various treatments. Where applicable research related to pedestrian operations and safety might be incorporated into intersection design is discussed. Although the Green Book is a policy and comprehensive coverage of all topic areas is not possible, some changes and short additions in areas such as sidewalks/walkways, refuge islands, and sidewalk flares are suggested to improve the information available to the designer.

Allowing vehicles and pedestrians to share the roadway environment safely and efficiently is not an easy task. The characteristics of these modes of travel are vastly different, and yet they compete for use of the same street and highway space. Typically there have been independent approaches to the design of highway and pedestrian facilities. In many places, highway congestion and pedestrian safety problems have become prevalent, indicating a critical need to assess the design process and search for effective means to integrate these independent design efforts. The American Association of State Highway and Transportation Officials' (AASHTO's) *A Policy on the Geometric Design of Streets and Highways* (*1*), often referred to as the Green Book, is the principal guidance for highway design decisions in the United States. Therefore, it is appropriate to examine this document to determine the potential for a broader view of the highway design process such that the needs of pedestrians are adequately addressed.

This paper examines the highway and street design process in the context of pedestrian needs. It attempts to determine

- Whether highway design standards adequately consider the pedestrian,
- Whether current design treatments are appropriate,
- Whether pedestrian facility designs are compatible with highway facility designs, and
- Needs for future research.

This paper focuses on the design of intersections where the competition for space is the most critical.

M. T. Pietrucha, The Pennsylvania Transportation Institute, The Pennsylvania State University, Research Office Building, University Park, Pa. 16802. K. S. Opiela, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

BACKGROUND

Effective roadway design involves establishing realistic design criteria and controls for the traffic being served. The designer must understand the full range of traffic to be accommodated by a design. For motor vehicles, this involves knowing the number and types of vehicles that will use an intersection. In the case of the pedestrian, this implies an understanding of the number and characteristics of the pedestrians who will use an intersection.

The AASHTO Green Book is one of the most widely used reference manuals on the design of highway facilities. The Green Book was published in 1984 as an update and consolidation of previous documents on the subject, and the 1984 edition was updated in 1990. The Green Book provides highway design guidance for the full realm of highway types and situations. Whereas it recognizes the needs of the pedestrian, the current edition does not adequately address all of the aspects related to providing safe and convenient conditions for the pedestrian. Since the Green Book is intended to be a policy, it cannot be expected to address every detail important to pedestrian-related design. However, more reference to pedestrian needs is essential to raise the consciousness of highway designers to pedestrian needs. The following sections provide some background on the general guidance provided by the Green Book relative to pedestrians.

CRITIQUE OF CURRENT GENERAL DESIGN GUIDELINES RELATED TO PEDESTRIANS

Highway Functions

Functional classification is used in the Green Book as the basis for determining the applicable criteria for street and highway design. The functional classes are defined in broad terms of movement hierarchies and relationships. In making these definitions, however, there is no mention of the movement of pedestrians. Whereas there may not be an exact pedestrian parallel for the AASHTO-defined six stages of a trip (i.e., main movement, transition, distribution, collection, access, and termination), elements of a pedestrian trip or a trip in which pedestrian movement represents an important element (e.g., the distribution or collection elements of a transit trip) certainly fit into this hierarchy. In the Green Book, the movement hierarchy sets the framework for the functional relationships for the vehicle trips. There may be a hierarchy associated with pedestrian trips, but this may be less critical than the presence or absence of pedestrians rel-

ative to design criteria for a roadway within each of the functional classes. This suggests that within each functional class there should be subclasses that reflect the impact of the presence of pedestrians on highway design and operation. Such a classification scheme would permit more rational guidance for the design of roads for the movement of both vehicles and pedestrians. In the absence of such criteria, the Green Book treats pedestrians in a haphazard manner. For example, whereas several of the chapters give limited guidance on provision of pedestrian access and the desirability of sidewalks, no specific criteria are offered to provide a basis for design decisions or to provide the justification needed for more extensive pedestrian treatments in special situations (e.g., around schools and near shopping areas).

The nature of pedestrian trips, and concomitantly some of the design decisions, vary by situation and somewhat according to the functional classification of the road. For example, lunchtime shoppers along an urban minor arterial have much different user characteristics and trip purposes than do schoolchildren walking along a local collector street to get to their school bus stop or commuters walking along the collector to get to the transit stop located on an arterial street. Highway designers need to recognize different pedestrian uses to make the most efficient use of the right-of-way to serve all uses. Beyond the need to serve different users, the designer must apply design criteria that promote safety and convenience. For example, the need for sidewalks and wide shoulders varies between collector and arterial streets to reflect differences in access. Similarly, the frequency of pedestrian crossings may dictate that medians become the norm for the urban arterial.

The need exists to establish guidelines for highway design that would apply where pedestrians represent a significant proportion of the traffic. For example, design and operational strategies for such a situation might be to control vehicular speeds, minimize vehicular impedance to the pedestrian, minimize pedestrian-vehicle conflicts, reduce conflicting attention demands, ensure adequate walkway separation, and provide aesthetic designs. These desired pedestrian pathway attributes would be emphasized rather than movement of vehicular traffic. Experience has shown that designers can find ways for vehicles and pedestrians to safely and conveniently coexist (*2*,*3*).

Pedestrian Characteristics

The Green Book recognizes the influence of pedestrian physical and behavioral characteristics on street and highway operations. Chapter 2 deals with the general characteristics of traffic and describes body area, walking rates, and walking capacities of pedestrians. Information is provided on average pedestrians as well as those with physical, visual, or mental handicaps. Walking capacities are discussed for sidewalks, stairways, and intersections, and two simple models are provided for determination of required pedestrian storage area at intersections, crosswalk widths, and level of service.

The Green Book accurately states that pedestrians are a major consideration of every roadway environment, urban and rural. However, it goes on to emphasize that they will most likely be found in urban areas, and, therefore, it is the urban pedestrian that most often influences design. There is a measure of truth in this statement, but walking occurs in suburban and rural areas, sometimes in significant volumes (*2*,*3*). However, the distinction between urban, suburban, and rural areas is not always clear. A consequence is that pedestrian movements take place in areas where they are not expected by drivers, and the roadway facilities do not adequately accommodate these movements. For example, in areas being developed on the suburban fringe, the pedestrian population may be especially at risk because sidewalks or shoulders have not been provided and traffic operates at higher speeds. Even where development is intense, an automobile orientation results in wide arterial cross sections, limited facilities for crossings, and barriers that prevent convenient pedestrian movement.

The Green Book may also indirectly discourage consideration of pedestrian needs. It describes the shopper as a pedestrian who is influenced chiefly by the "weather or advertised sales." They are described as "unpredictable, obstinate, ignorant, inattentive, or defiant." Some of this may be true, but one must also consider that pedestrians are unprotected, slow moving, and extremely fragile.

Physical Characteristics

The human body dimensions (an ellipse of 24 × 18 in.) in the Green Book are based on the work of Fruin (*4*) and are consistent with those used in the 1985 *Highway Capacity Manual* (HCM) (*5*). There is widespread agreement on these dimensions, but they do not take into consideration the increased body ellipse needs of the elderly with canes or walkers or adults with shopping carts or baby carriages. The need to design for this element of the pedestrian constituency may be small, but the designer should be aware of these diverse user groups in some situations.

The Green Book states that walking rates are generally 2.5 to 6.0 ft/sec with an average of 4.0 ft/sec in accordance with the 1988 *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) (*6*). It even goes so far as to state that in areas where there are many older people, a walking rate of 3.0 ft/sec should be considered. However, other studies have shown a wider range in walking rates. McShane and Roess suggest a range of approximately 2.5 to 8.0 ft/sec (*7*), and Bowman et al. give an average walking rate of 4.5 ft/sec (*8*). In fact, if one assumes a walking speed of 4.5 ft/sec to determine pedestrian clearance interval, 78 percent of the pedestrians observed in one study would have to quicken their walking speed to safely cross the street during the green indication. A current Federal Highway Administration (FHWA) study dealing with older-pedestrian characteristics should yield some useful information about this subject (Contract DTFH61-91-C-00028, being performed by the Center for Applied Research, Inc., Great Falls, Virginia).

Handicapped Pedestrian Characteristics

It is correctly noted in the Green Book that pedestrians with ambulatory difficulties are especially sensitive to stairs, curbs, or other horizontal obstructions that are in their paths. Recent research shows that such pedestrians are also sensitive to the type and condition of the walking surface. Kulakowski et al.

(*9*) have found that handicapped walkers require higher levels of walking-surface friction than the nonimpaired walker. The more important finding may be that the friction needed to safely traverse these pathways frequently exceeds the obtainable friction coefficients for many walking surfaces. These findings may also have implications for the section of the Green Book dealing with pavement surface types.

As stated in the Green Book, pedestrians with vision problems require special consideration, but these are not limited to just the texturized pavement marking treatments mentioned therein. There is some indication (based on a relatively small sample of blind pedestrians) that visually handicapped pedestrians prefer curb corners to be more angular (i.e., shorter comer curb radii) to give them better directional orientation around the intersection (*10*).

Walkways

The Green Book outlines the design requirements for walkways. It notes that walkways or sidewalks are commonly considered as part of the street cross section in urban areas, but few are provided in rural areas. The Green Book suggests that the need in rural areas in great because of higher speeds on rural roads and the general inadequacy of lighting. It recommends that sidewalks or walkways be installed in rural and suburban areas to connect community activity areas (i.e., schools, shopping, and residential areas). It notes that sidewalks may not be required in the initial development stages but that adequate provisions for future inclusion are needed. Shoulder treatments may suffice temporarily, but the right-of-way planning should include space for a sidewalk separated from the shoulder, a buffer or border area, and adequate clearance for adjacent land uses. Sidewalks are recommended to be 4 to 8 ft in width with a minimum of 2 ft of clearance or separation. The justification for providing such pedestrian facilities in suburban and rural areas should be based on the volumes of traffic, the relative timing of demand, and speeds.

The Green Book provides other recommendations for general practice relative to walkways, including the following:

- Sidewalks should be provided along any highway without shoulders to keep pedestrians from using the traffic lanes.
- Crosswalks should be marked where the pedestrian paths between community activity areas intersect streets and highways.
- The connectivity of walkways should be maintained where community activity areas are close together.
- Walkway designs should accommodate the elderly and handicapped.
- Special treatments are needed for bridges to provide a safe transition and to provide railings and fences along the bridge walkpath.
- Barrier curbs should be provided on low-speed roads and full barriers on high-speed roads where the pedestrians are close to the traffic.

These guidelines, while useful, provide neither adequate quantitative criteria nor full integration into the facility design process.

The Green Book offers information related to the capacity of walkways but does not address the more significant pedestrian capacity problems at intersections. As with the roadway, the system bottlenecks usually occur at the node points in the network.

Although the Green Book gives a short description of pedestrian flows and operations at an intersection, it does not give the designer an adequate feel for what can be expected in these situations. The Green Book briefly discusses holding areas for queued pedestrians, crosswalk widths, and the use of traffic control devices to create gaps in the traffic stream that will allow for pedestrian crossings. This would lead the designer to think that pedestrian capacity is based solely on area or space considerations. The capacity analysis technique prescribed by the HCM (*5*) is based on a time-space concept that considers pedestrians waiting to cross the street, pedestrians crossing the street, and pedestrians who use the corner to circulate through the pedestrian network without entering the street (i.e., people walking around the corner). Each of these categories places a different demand on the time-space capacities of the corner (e.g., pedestrians waiting to cross the street take up more time and less space than pedestrians moving around the corner who need more space but less time). The current policy should be revised to give a fuller description of the technique so that the designer is aware that pedestrian volumes and pedestrian flow rates are important factors in the design process.

Crossings

The Green Book provides some guidance relative to pedestrian crossings, but this information deals mostly with separated crossings. It suggests that separated crossings may be required where pedestrian volume, traffic volume, intersection capacity, or other conditions "favor" such a treatment. It suggests that an individual study of each situation is needed to consider heavy peak movements, abnormal hazards, or a combination of these factors to decide on the need for a separated crossing. Several general design guidelines for over- and underpasses for pedestrians are provided.

CRITIQUE OF CURRENT DESIGN GUIDELINES FOR AT-GRADE INTERSECTIONS

After establishing the basics of functional classifications and design controls in the first two chapters, the Green Book addresses elements of design, cross-sectional features, and specific design standards for local roads and streets, collector roads and streets, rural and urban arterials, and freeways. There are valid pedestrian concerns related to each of these areas that would warrant a careful scrutiny of these chapters, but this paper focuses on Chapter IX, At-Grade Intersections.

Intersection Types

The discussions of the various types of intersections in this section make only limited mention of pedestrians. A simple

discussion of how pedestrians would function as part of these different intersections would go a long way toward sensitizing the designer to pedestrian needs. For example, there is a discussion of how skew affects the operation of the intersections from a turning vehicle perspective; however, there is no mention of how skew will affect pedestrian operations (e.g., create longer crossing distances and greater pedestrian exposure).

The Green Book describes various types of basic and enhanced intersection designs, but it does not consider the variety of design treatments that have been used to accommodate pedestrians in real-world situations. For example, sidewalk flares (see Figure 1) can be constructed. They offer the advantages of shorter crossing distances, more pedestrian visibility, a better view of traffic for pedestrians, and sidewalk space for queuing, but reduced right-turn capacity and corner drainage problems are disadvantages. Coverage of design considerations for this type of treatment is given by Pietrucha and Plummer (*11*).

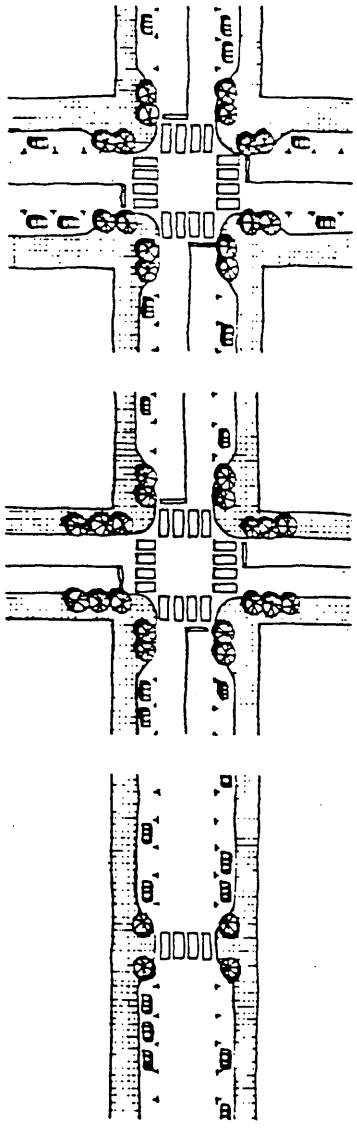

FIGURE 1 Intersection design treatments: *top*, full-corner flare; *middle*, half-corner flare; *bottom*, midblock flare.

Capacity Considerations

The Green Book indicates that the vehicular capacity of intersection designs needs to be evaluated using procedures outlined in the HCM (*5*). The HCM also offers an extensive treatment of pedestrian capacity for sidewalks, crosswalks, and street comers. Procedures are presented in the HCM for applying the level of service (LOS) criteria outlined to walkways, queuing areas, street corners, and crosswalks. The latter two are noted as the most difficult to analyze due to the diversity of movements and the high volume of pedestrians. The procedures outlined allow for the determination of a LOS measure based on pedestrian volumes, walkway width, crossing times, crosswalk areas, surge factors, and circulation times. Since the design process typically involves iterative analyses of capacity adequacy and design feasibility, the need exists to develop an integrated approach that will include both pedestrian and vehicular capacity considerations.

Alignment and Profile

The Green Book initiates the section on alignment and profile by noting that intersections are points of conflicts between vehicular and pedestrian traffic juxtapositioned on a specific environment. It is certainly true that vehicle-pedestrian conflicts do occur at intersections; however, no further guidance is provided to ensure that intersection alignments are set in a manner that enhances the safety and convenience of the pedestrian. For example, the Green Book recommends the intersection of roadways at 90-degree angles. However, it should also mention that this design standard represents the best option for both pedestrian and vehicular traffic. Sight lines are optimal, conflict space is limited, and crossing distances (and hence exposure time) are reduced.

The profile of intersection approaches receives only cursory attention, but it is another complicating factor. The sight lines of traffic approaching an intersection on a significant grade are compromised. This limits the opportunities for the pedestrian and the motorist to assess a situation.

A fundamental problem with the Green Book is that its criteria are specified in a two-dimensional format. Whereas this may be a necessity for presentation, in reality the sight lines are further complicated by other objects at or near the intersection and the viewing position of the driver or pedestrian. For example, the view of a driveway or sidewalk for a truck driver with an eye height of 6 ft may be impaired by trees planted along the right-of-way. A two-dimensional view might otherwise indicate adequate sight lines. Pedestrians in a crosswalk may not be fully visible in such a situation.

Intersection Curves and Turning Radii

Chapter III of the Green Book provides guidance on the design of curves. Fundamentally, an appropriate curve radius is a function of traffic speed and volume and traffic mix. The Green Book presents appropriate turning radii for various vehicle types. The critical factor is inner wheelpath during a turn, particularly for long vehicles. The Green Book specifies an envelope for turns by larger vehicles, but it does not define a buffer zone that would help define an adequate intersection design. This buffer zone would indicate an area unsafe for pedestrians. It should be something greater than the inner wheelpath, since not all drivers negotiate a curve in the same manner. The Green Book indicates the potential need to acquire additional right-of-way to accommodate pedestrians at intersections and preferred sidewalk-curb radii at intersections. These are discussed only in the context of urban arterial intersections.

The Green Book also sets standards for the design of intersections with turning roadway elements. These can pose a hazard to pedestrians, since they promote faster traffic speeds. The Green Book does not offer any guidance on the optimal location of pedestrian crossing on these, although it is generally accepted that right angle crossings are the best.

Islands and Medians

Medians and refuge islands (see Figure 2) are other features important to pedestrians that have not been fully described in the design standards. They reduce crossing delay and increase pedestrian safety by separating conflicts, controlling angle of conflict, reducing pavement areas, regulating traffic

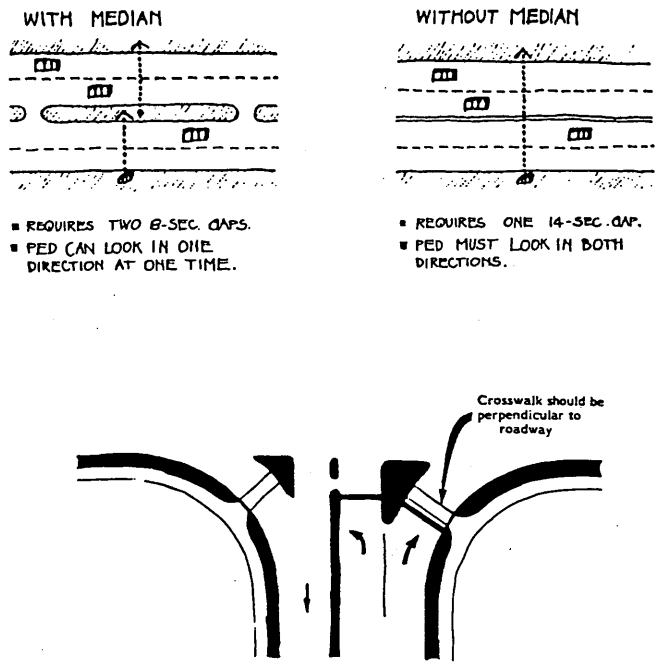

FIGURE 2 Typical intersection design treatments to accommodate pedestrians.

by indicating proper use of an intersection, favoring particular turning movements, protecting pedestrians, protecting and storing turning and crossing vehicles, and providing space for the location of traffic control devices.

The Green Book describes various types of intersection islands and offers guidance on their use but provides only limited attention to refuge islands. Its principal deficiency is the lack of design details and criteria for the use of refuge islands. The size, configuration, and integration of other elements need to be addressed in the context of the number and types of pedestrians that will be using the facility and the type of road on which it is placed. This section also provides inadequate examples of the proper use of refuge islands (e.g., Figure 2).

Generally, pedestrian refuge islands should be used to facilitate the movements of pedestrians across wide streets or to protect pedestrians in areas of the intersection where there may be complicated (e.g., irregularly shaped, skewed), confusing traffic flow patterns, or segregated, high-volume vehicle movements (e.g., turn lanes). The island also provides a stopping point for the slow walker who cannot cross the entire street in the allocated pedestrian time. At isolated signal locations, the reduced pedestrian clearance time can minimize the signal cycle length and the overall delay to vehicular traffic. It has been proposed that pedestrian refuge islands be provided when the total length of a crosswalk is greater than 75 ft or in areas where there are many elderly or handicapped pedestrians. Refuge islands should be provided if the intersection cannot be crossed in the walk/green time allotted for the pedestrian movement using an assumed walking rate of 3.5 ft/sec (*8*). This also assumes that the signal timing cannot be changed to accommodate these special pedestrians. Islands should be designed to make the approach clearly visible, allow sufficient time for driver and pedestrian decision making, and ensure that the path and approach conditions follow the natural path of movement.

The Green Book offers information regarding minimum sizes for refuge islands based on the need to give pedestrians a sense of security when they are near moving traffic. The recommended minimum is 4 ft and the preferred width is 6 ft for pedestrian refuge islands (*8*). The length of the refuge island should be a function of the use of the island; however, median-type refuge islands should be at least 12 ft long (*8*).

If the refuge island is to be a raised barrier curb design, there must be a pedestrian travel path through the island, or there must be sufficient space for curb ramping and a level waiting area large enough for a wheelchair (*8*). The objective in the design of islands from a pedestrian point of view is to provide a traversable path. The designer needs to be mindful of details such as curb heights (for older and younger pedestrians); pedestrian volumes; surface types; and locations of traffic signal hardware, luminaire supports, ramps, and inlet grates.

The Green Book chapter Cross Section Elements describes a median as a device that controls vehicle movements or stores stopped vehicles. This discussion should include information on the use of medians as refuge areas for pedestrians. One of the major problems that pedestrians face, especially older pedestrians, is the crossing of wide streets. At unsignalized intersections, medians allow the pedestrian to perform a simplified crossing task. The pedestrian can accept smaller gap

in the traffic stream, and the task is simplified by having to locate gaps in traffic coming from only one direction (Figure 2). At signalized intersections, because of traffic control considerations, the available pedestrian crossing time is usually the minimum specified in the MUTCD and the *Traffic Control Device Handbook* (*12*). Many pedestrians do not walk at speeds used for design purposes (4.0 ft/sec), and slower walkers have very little time to traverse a wide intersection. If the minimum pedestrian indication times were set at lower walking speeds, the time allocated for this "minor" traffic movement would put the major traffic movement at a disadvantage. In cases where it is desirable to maintain a minimum pedestrian crossing indication, a median would provide a place for pedestrians to safely stop and continue their crossing during the next pedestrian indication. Whereas this type of operation is less than ideal, especially from the pedestrians' point of view, it provides a solution to a common problem. The need also exists for treatments to discourage improper use of medians by pedestrians (e.g., pedestrians can be observed walking laterally along medians to capture the next available gap in traffic, which violates a basic tenet of traffic engineering—control the number of possible conflict points).

Traffic Control Devices

The Green Book appropriately indicates that design and control treatments for intersections must be developed in concert. The geometry and cross section of an intersection need to be considered in conjunction with options for traffic control devices (TCDs)—signals, signs, pavement markings, and street furniture. The nature of the vehicular and pedestrian traffic must, of course, dictate the selection of appropriate design and control treatments. The following paragraphs discuss some of the interactions associated with pedestrian-sensitive design and control of intersections.

Flow Control

It is well known that TCDs can be used to create artificial gaps in the vehicular traffic so that pedestrians can cross the road. The policy states that if there are no controls the pedestrian must wait for a sufficient gap to cross. However, there is no guidance for the designer regarding the definition of a sufficient gap. Analytically, one could reason that a sufficient gap could be based on the pedestrian crossing distance, d_c (ft), and an assumed pedestrian walking speed, s_p (ft/sec). This would yield a gap time that is equal to d_c/s_p (sec). There is also a need to include some amount of pedestrian start-up time (t_{psu}, sec) in this measure of gap time [e.g., 4 to 7 sec (*6*)]. As with intersection sight distance calculations, this time could then be converted into a pedestrian sight distance requirement (d_p) based on roadway design speed. This concept could have serious implications on how highway designers determine intersection sight distance.

For example, consider the intersection sight distance requirements at a stop-controlled intersection for Case IIIB, Turning Left into a Major Highway, in the Green Book (*1*). This condition is assumed because it gives the maximum intersection sight distance dimension that can be required at an intersection. If one assumes a roadway with a 50-ft curb-to-curb width and a design speed of 50 mph and determines from the appropriate sources in the Green Book the values for t_p and P, the required intersection distance to the right of the turning vehicle would be approximately 725 ft:

$$d = Q - h \tag{1}$$

where

- d = required passenger car sight distance to the right along the major road from the intersection (ft);
- Q = $1.47(0.85)V\ (J + t_p)$ (for this example the value is calculated to be 1,062 ft);
- h = $P - 16 - [1.47 * 0.85 * V\ (J)] - L$ (for this example the value is calculated to be 340 ft);
- V = design speed of the major highway (mph) (for this example, the value is 50 mph);
- J = sum of the perception time and the time required to actuate the clutch or an automatic shift [for this example, the value is assumed to be 2 sec (*1*)];
- t_p = time required to travel the distance P (sec), taken from Green Book Table IX-7 (*1*) (for this example, the value is estimated as 15 sec);
- P = distance for the turning vehicle to reach a speed 85 percent of the mainline design speed, taken from Green Book Figure IX-34 (*1*) (for this example, the value is 500 ft); and
- L = overall length of the vehicle (ft), assumed to be 19 ft for passenger cars (*1*).

If one follows the conceptual argument for pedestrian sight distance, which is advanced above, for the same set of conditions the required pedestrian sight distance would be approximately 1,215 ft:

$$d_p = 1.47\ V[(d_c \div s_p) + t_{psu}] \tag{2}$$

where

- d_p = required pedestrian sight distance to the right along the major road from the intersection (ft),
- d_c = pedestrian crossing distance (for this example, the value is 50 ft),
- s_p = pedestrian walking speed [for this example, the value is assumed to be 4 ft/sec (*1*)],
- V = design speed of the major highway (mph) (for this example, the value is 50 mph), and
- t_{psu} = pedestrian start-up time [for this example, the value is assumed to be 4 sec (*6*)].

As shown in this example, the required intersection sight distance for the vehicles turning left is considerably less than the required pedestrian intersection sight distance.

Even if the pedestrian could make the crossing (under the same lane width and design speed conditions) in two stages (breaking up the crossing into two parts by means of a pedestrian refuge island), the pedestrian sight distance to the left would still be less than the maximum required vehicle sight distance [approximately 735 ft for the pedestrian maneuver compared with approximately 725 ft for a vehicle turning right onto a major road from a standing start (Case IIIC,

Turning Right into a Major Highway, in the Green Book (*1*)]. One may argue that the difference is hardly worth noting. However, one must keep in mind that the values for walking speed and pedestrian start-up time used in this example are in the conservative range. This whole argument might be considered moot when one considers a pedestrian's ability to see and detect motion of an object that is more than 700 ft away.

Device Application

Chapter IX of the Green Book is not intended to give exhaustive coverage to TCDs, and it appropriately reminds the designer that space must be provided for TCDs, including those for the pedestrian. Two important features that could influence the design of the intersection should be covered in this Green Book chapter. A properly designed intersection cannot function without properly designed pavement markings, in particular, crosswalk markings and stop bars. The size and placement of these devices could influence the size or placement of other geometric features of the intersection. They should also be considered as possible future additions to any intersection.

Although specific design requirements are not given for other TCDs, some general guidance concerning the size and placement of crosswalks and stop bars should be provided for the designer. Generally, crosswalks should be at least 6 and preferably 10 ft in width. There cannot be much choice about the length; however, for long and hazardous crossings, the crosswalk may need to be augmented with other devices such as curb flares or refuge islands. Stop bars are used to stop vehicles from encroaching on the crosswalk. They are usually 12 to 24 in. wide. They are placed 4 ft in advance of the crosswalk. In many instances, a staggered setup can be useful in providing better sight lines for vehicles that are turning right on red.

As with many of the other sections of the Green Book, the discussion on traffic barriers focuses entirely on vehicular traffic. Many different types of barriers provide an effective means of channeling pedestrian flows and prohibiting, or at least making more difficult, undesired pedestrian movements. Zegeer (*10*) presents a series of conditions in which barriers may be most useful along with a listing of potential advantages and disadvantages. Whereas this information should not be a principal focus of this section, it certainly deserves some mention in the Green Book.

Other Controls

Some analyses have shown that 50 percent of all urban pedestrian accidents involve dashes into the street at midblock locations or intersections (*11*). A frequently cited contributing factor with these types of accidents is that the motorists or pedestrians could not see each other because of on-street, parked cars. The designer should consider the prohibition of on-street parking near intersections. In cases where vehicle travel speeds are 35 mph or greater, it has been recommended that this distance be at least 100 ft (*8*). This section of the Green Book needs to be revised to include some discussion of pedestrian accident problems associated with on-street parking.

Similarly, turn restrictions can be considered to control traffic at an intersection. The provision of indirect left turns and indirect U-turns creates a wider crossing area than standard, small-radii turns. There should be some mention of the problems these types of designs can create for pedestrians in the Green Book.

The Green Book does not address traffic controls for school zones. Only general guidelines are provided for the use of flashing beacons, crosswalks, traffic signals, and grade separation structures. Some coverage of this special pedestrian group analogous to what is covered in the MUTCD should be considered.

Channelization

The Green Book offers a short section on channelization in Chapter IX. It makes reference to considering pedestrians, but the 10 principles presented for channelization fail to mention the pedestrian. A similar set of points would be appropriate to reflect the pedestrian's perspective of the intersection.

Cross Section Design

The entire section of the Green Book dealing with cross section elements considers design in terms of vehicular traffic only. Whereas many suburban and rural roads have little pedestrian traffic, people do walk on these roads. This is evidenced by the fact that approximately 15 percent of the pedestrian accidents in these areas occur when a pedestrian is struck while walking along a roadway (*2*). Design criteria related to several cross section elements should be reexamined to see whether changes need to be made to accommodate the pedestrian.

Pavement Cross Slope

The Green Book specifies that the normal pavement cross slope can range from 1.5 to 6 percent for properly draining the pavement. The higher values in this range may make walking a path parallel to the centerline of the roadway awkward, causing the pedestrian to walk where the slope flattens out—that is, nearer to the traveled way.

Lane Widths

The Green Book principally addresses the subject of lane widths in terms of the vehicular traffic because of their effect on highway capacity. Better guidance regarding the widths of lanes, especially the use of narrower lanes (i.e., 10 or 11 ft), is needed since the roadway is often shared by pedestrians and vehicles.

Shoulders

In the Green Book, the shoulder is only thought of as an area for stopped or disabled vehicles and as a structural element that laterally supports the roadway. Even though the use of the shoulder by pedestrians is to be discouraged in many situations, it must be realized that, despite the misgivings of the highway designer or traffic engineer, people walk there. Any design decisions regarding shoulders should consider pedestrian use and be made in concert with decisions regarding lane widths.

Curbs

This section of the Green Book should remind the designer that a curb is also a barrier to some pedestrians. Handicapped and older pedestrians find it difficult to negotiate high sections of barrier curb. Whereas pedestrian ramps can be part of a solution to this type of problem, they are not referenced in this section of the Green Book.

Walkways

Whereas the Green Book correctly states that there are no pedestrian or vehicular traffic based sidewalk warrants, a set of guidelines for the installation of sidewalks has been proposed by Knoblauch et al. (*13*). These guidelines are based on a study of pedestrian accidents related to pedestrian exposure and certain operational and design features. The study makes recommendations relative to land use category, roadway functional class, and development density for both new and existing urban and suburban streets. Because there are no formal guidelines for providing sidewalks in rural areas, the direction given in the Green Book provides sound but not definitive advice.

Wheelchair Ramps at Intersections

In the Green Book, the designer is referred to Chapter IV for direction in the design of wheelchair ramps at intersections. The treatment of this topic is woefully inadequate. Simple, effective designs are plentiful; however, inconvenient, poor-draining, dangerous ramps abound. For more complete coverage of this important topic, the designer should be referred to the FHWA implementation manual on this subject (*14*).

Driveways and Access Management

Chapter IX of the Green Book includes a section on driveways and notes that this type of feature is, in effect, an intersection. A serious deficiency of the Green Book is its treatment of driveways. The Green Book provides only limited attention to measures that can be applied to control access along major roadways. The goal of access control is to provide improved traffic flow and increased safety on streets and highways. Whereas sidewalks may have a consistent surface material across driveways, there is little else to warn, direct, or control the flow of vehicular or pedestrian traffic. Access control measures should be considered in the design of highways for the benefit of both vehicular and pedestrian traffic.

SUMMARY

This paper critiqued the AASHTO Green Book, focusing primarily on Chapter IX, At Grade Intersections. The fundamental findings of this critique are as follows:

1. The Green Book, though not silent on the subject of pedestrians, provides only limited guidance to the highway designer. It describes basic characteristics but does not cover the range of characteristics or the extent of pedestrian travel.
2. The Green Book is predominantly vehicle oriented. In many cases, provisions for pedestrians or other modes that share the highway right-of-way appear to have been added as afterthoughts.
3. The Green Book does not present a fully integrated approach to highway design. The nonmotorized modes, in particular, are not given adequate treatment, nor are the safety, traffic flow, or cost aspects of these modes given sufficient attention.
4. The Green Book is developed around a functional classification scheme related to vehicular traffic. This scheme does not effectively incorporate considerations for nonmotorized modes or the transitional nature of the highway environment.
5. The Green Book needs updating to reflect recent design and warrant criteria related to pedestrian facilities.
6. The Green Book provides only limited coverage of design treatments for intersections, islands, and medians. More attention is needed to promote their application to address pedestrian needs.
7. Separate sections dealing with pedestrians are not necessary. Passages regarding the pedestrian's place in the movement hierarchy and the functional relationships could be woven into the existing text.

It is not expected that highway designers will become experts about pedestrian design, but it is recommended that they devote more attention to the pedestrian as part of the total design process. There are similarities and differences in the design considerations for highways and pedestrians, as noted in Table 1. For example, the principles that apply to highway channelization apply to pedestrians as well. The vulnerability of the pedestrian in the intersection environment dictates that the highway design process, at least, explicitly assess the pedestrian. Ideally, the intersection design process would use a dual perspective approach to channelization that would better integrate all modes. These differences in design consideration are critical to the safety and convenience of the pedestrian. For example, crossing a major arterial poses a major risk and difficulty for pedestrians. Some approaches to the design of arterials focus on maximizing the provision of traffic lanes within the right-of-way. The provision of medians limits the lane configuration options and complicates the design, but it offers clear advantages to the pedestrian. Improvements to the Green Book that would encourage or help the highway

TABLE 1 Facility Design Criteria

	Considerations Associated with Design Elements	
	Roadway	Pedestrian Facility
ROW Width	o Capacity dictates number of lanes o Standard widths by functional class o Minimize land acquisition costs o Future improvement options	o Fruin's work defines required space o Amenity space desirable o Pathway alignment influenced o Pathway separation influenced
Lane Configuration Cross Section Number of Lanes Medians	o ROW limits o Capacity dictates number of lanes	o Curbs an impediment to pedestrians o Barriers may enhance pedestrian safety
Horizontal Alignment	o Terrain usually dictates o Adequate sight lines	o Minimize grade differentials o Locate crossing to maximize visibility
Channelization	o Minimize conflicting movements o Enhance capacity o Minimize delay o Enhance signal effectiveness	o Islands provide refuge to pedestrians o Pedestrians must deal with faster traffic o Queuing space affected
Drainage	o Minimize surface water	o Minimize puddles o Avoid placing drainage structures in pedestrian paths
Vertical Alignment	o Provide safe stopping distances o Provide adequate drainage o Provide smooth transitions between grades	o Pedestrian exposure may be more critical o Locate crossings with adequate sight lines
Turning Radii	o Increased radii mean higher speeds o Facilitates the turning of larger vehicles	o Increases pedestrian walking distances o Affects queuing space o Complicates pathway connections
Ancillary Facilities (Bus stops, parking)	o Minimize operational impacts o Minimize traffic impediments	o Board/alight passengers at safest point o Assure that pedestrians are visible around parked vehicles
Structures	o Provide adequate laneage	o Provide adequate separation from traffic o Provide physical separation where needed

design "think about the pedestrian" would promote safer and more convenient designs. It is not out of the question for the Green Book to present guidelines for the design of pedestrian facilities, since these most often occur within highway rights-of-way.

RESEARCH NEEDS

There are a number of topics related to integration of pedestrian needs into highway design. Some of these are as follows:

- It is necessary to investigate the functional classification scheme used in the Green Book to determine whether a new scheme could be devised that considers both vehicles and pedestrians.
- Increased roadway costs may result from incorporating features for the pedestrian. A thorough analysis of the life cycle costs and benefits of such actions would be useful in establishing pedestrian-sensitive design standards.
- The modifications of basic highway design features or the incorporation of other features can result in added maintenance costs. There is a need to determine how these features can be designed to minimize maintenance needs and costs.
- A major difficulty in improving streets and highways to better accommodate the pedestrian is the extent of current facilities and established access patterns. The need exists to find effective concepts for the retrofitting of highways to accommodate the pedestrian.

To address the questions posed at the outset of this paper, a structured critique of the highway design process is necessary. The design process must be geared to the primary objective of providing safe and convenient movement for both vehicles and pedestrians.

REFERENCES

1. *A Policy on Geometric Design of Highways and Streets*. American Association of State Highway and Transportation Officials, Washington D.C., 1990.
2. S. A. Smith, K. S. Opiela, L. L. Impett, M. T. Pietrucha, R. L. Knoblauch, and C. Kubat. *Planning and Implementing Pedestrian Facilities in Suburban and Developing Rural Areas*. National Cooperative Highway Research Program Report 294A: Research

Report. TRB, National Research Council, Washington, D.C., June 1987.
3. S. A. Smith, K. S. Opiela, L. L. Impett, M. T. Pietrucha, R. L. Knoblauch, and C. Kubat. *Planning and Implementing Pedestrian Facilities in Suburban and Developing Rural Areas*. National Cooperative Highway Research Program Report 294B: State-of-the-Art Report. TRB, National Research Council, Washington, D.C., June 1987.
4. J. J. Fruin. *Pedestrian Planning and Design*. Metropolitan Association of Urban Designers and Planners, Inc., New York, 1971.
5. *Special Report 209: Highway Capacity Manual*. TRB, National Research Council, Washington, D.C., 1990.
6. *Manual on Uniform Traffic Control Devices for Streets and Highways*. U.S. Department of Transportation, 1988.
7. W. R. McShane and R. P. Roess. *Traffic Engineering*. Prentice-Hall, Englewood Cliffs, N.J., 1990.
8. B. L. Bowman, J. J. Fruin, and C. V. Zegeer. *Planning, Design, and Maintenance of Pedestrian Facilities*. Federal Highway Administration, U.S. Department of Transportation, 1988.
9. B. T. Kulakowski, P. R. Cavanaugh, L. F. Geschwinder, F. Buczek, and P. Pradhan. *Slip Resistant Surfaces Research Project, Volume 1: Technical Report*. Pennsylvania Transportation Institute, University Park, Pa., 1988.
10. C. V. Zegeer. *Synthesis of Safety Research—Pedestrians*. Federal Highway Administration, U.S. Department of Transportation, 1991.
11. M. T. Pietrucha and C. W. Plummer. Design Considerations for Pedestrian Sensitive Geometric Features. In *1992 Compendium of Technical Papers*, Institute of Transportation Engineers, Washington, D.C., 1992.
12. *Traffic Control Device Handbook*. U.S. Department of Transportation, 1983.
13. R. L. Knoblauch, B. H. Tustin, S. A. Smith, and M. T. Pietrucha. *Investigation of Exposure Based Pedestrian Accident Areas: Crosswalks, Sidewalks, Local Streets and Major Arterial*. Report FHA/RD-88/038. Federal Highway Administration, U.S. Department of Transportation, 1988.
14. J. A. Templar. *Provisions for Elderly and Handicapped Pedestrians: Development of Priority Accessible Networks, An Implementation Manual*. Federal Highway Administration, U.S. Department of Transportation, 1980.

Publication of this paper sponsored by Committee on Geometric Design.