TREATMENTS FOR DESIGNING URBAN ROADWAYS FOR THE AGING POPULATION

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ABSTRACT

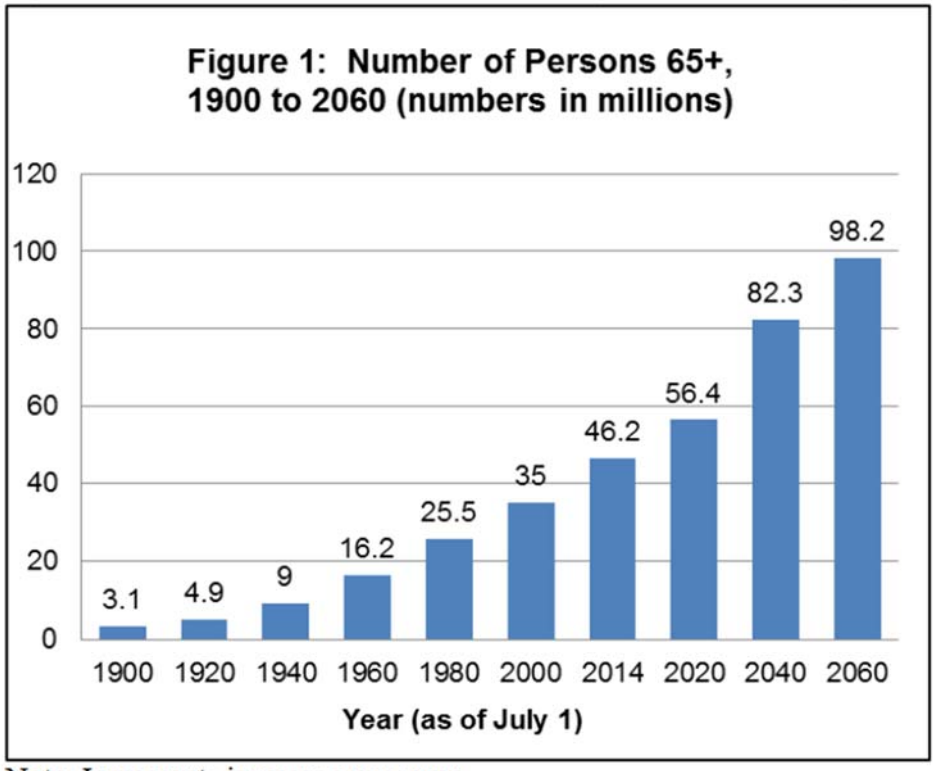
An increasing number and proportion of the United States' population is part of the 65-and-older age group, with associated increases in the number and proportion of drivers and pedestrians in the same age group. It is estimated that there will be approximately 82.3 million persons in that age group in the United States by 2040, accounting for over one-fifth of the population in this country. In effect, for many aspects of road planning and design, the "design driver" and the "design pedestrian" of the early 21st century will likely be 65 or over. A recent publication by the Federal Highway Administration, *Handbook for Designing Roadways for the Aging Population*, is intended to provide practitioners with information on a wide variety of treatments for improving the safety and mobility of older road users. The *Handbook* contains details on 51 proven and promising practices in five categories: intersections, interchanges, roadway segments, construction/work zones, and highway-rail grade crossings. Supporting information (previous research, existing guidance, etc.) is also documented for each treatment. This paper highlights treatments particularly applicable to the urban street environment that are contained within the *Handbook* and the accompanying *Desk Reference* to the *Handbook*.

BACKGROUND

The increasing numbers and percentages of aging persons using our nation's streets and highways in the decades ahead will pose many challenges to transportation engineers who focus on safety and operational efficiency. According to the Administration on Aging, the 65-and-older age group numbered 39.6 million in the United States in 2009 (*1*) and 46.2 million in 2014 (*2*). By 2040, it is projected that there will be approximately 82.3 million persons aged 65-and-older (see FIGURE 1), accounting for 21.7 percent of the population of this country. In effect, for many aspects of road planning and design, the "design driver" and the "design pedestrian" of the early and middle 21st century will likely be 65 or over.

There are important consequences of these changing demographics, and life for aging persons depends to an extraordinary degree on remaining independent, which requires mobility. In our society the overwhelming choice of mobility options is the personal automobile. Other mobility options that may be used include public transit and walking. This means that there will be a steadily increasing proportion of drivers and pedestrians who experience declining vision; slowed decision-making and reaction times; exaggerated difficulty when dividing attention between traffic demands and other important sources of information; and reductions in strength, flexibility, and general fitness.

In a proactive response to this pending surge in aging road users, the Federal Highway Administration (FHWA) published the *Older Driver Highway Design Handbook* (*3*) in 1998. The 1998 *Handbook* provided highway designers and engineers with the first practical information source linking age-related declines in functional capabilities to enhanced design, operational, and traffic engineering treatments, keyed to specific roadway features. The *Handbook* was revised in 2001 (*4*) based on experience and feedback from practitioners. Now, a third edition of this resource has been prepared, under a new title, *Handbook for Designing Roadways for the Aging Population* (*5*). This updated resource incorporates new research, expands the range of applications covered by the *Handbook*, and introduces format changes—including a web-based version—that will facilitate access and use by engineering professionals to improve streets and highways in the years ahead.



Note: Increments in years are uneven.
Source: U.S. Census Bureau, Population Estimates and Projections.

FIGURE 1 Number of persons 65+: 1900-2060 (numbers in millions). (*2*)

Part I of the *Handbook* retains its focus on five broad categories of roadway features, each containing a number of specific design elements for which guidance is presented. The top priority is *intersections*, reflecting aging drivers' most serious and enduring crash problem area, as well as the greatest exposure to risk for pedestrians. Next, well-documented difficulties with merging/weaving and lane changing maneuvers focus attention on *interchanges*. *Roadway segments*, with an emphasis on curves and passing zones, plus *highway construction/work zones*, are included due to heightened tracking (steering) demands that may increase a driver's workload along with an increased potential for unexpected events that require a rapid response. Finally, *highway-rail grade crossings* merit consideration as sites where conflicts are rare, and thus unexpected, and where problems of detection (with passive controls) may be exaggerated due to sensory losses with advancing age.

The treatments presented in Part I are followed by a more lengthy section, Part II, presenting the rationale and supporting evidence for each treatment. Preceding the treatments, a chapter titled "How To Use This *Handbook*" explains codes used throughout the document to cross-reference the *Manual on Uniform Traffic Control Devices (MUTCD)*, AASHTO's *A Policy on Geometric Design of Highways and Streets* (the *Green Book*) and other manuals and guides. In addition, a guide for interpreting graphics used in the *Handbook* and a table for translating speeds and distances into "preview times" for driver decision and response selection are presented, and a structured approach to help engineering professionals decide when to implement *Handbook* treatments is described. A supplementary discussion about how to determine the visibility of roadway elements is appended to this edition of the *Handbook*. The *Handbook* concludes with a glossary providing definitions of selected terms and a reference list.

Most of the treatments in the *Handbook* are based on supporting evidence drawn from a comprehensive review of field and laboratory research addressing human factors and highway safety. The supporting information presented in Part II represents the latest relevant information and data available to the authors at the time the document was assembled. This edition also includes some "Promising Practices"—treatments that are being used by one or more agencies, which, although they have not been evaluated formally, are generally believed to benefit the aging population of roadway users based on subjective assessment by the staff participating in the development of the *Handbook*. This conservative approach also dictated that the *Handbook's* treatments relate to the demonstrated performance deficits of *normally aging* drivers and pedestrians. It deserves mention that diminished capabilities that result from the onset of Alzheimer's disease and related dementias, which may afflict over 10 percent of those age 65 and older and over 40 percent of those age 85 and older, are not explicitly targeted in these guidelines. Neither are the compromises in performance that are associated with drowsiness, fatigue or distraction.

In addition to the *Handbook*, there is a companion *Desk Reference* (*6*), which is a concise guide that provides important information on Part I of the *Handbook*. These resources can be applied preemptively to enhance safety wherever there are aging road users in a given jurisdiction, or they may be employed primarily as a "problem solver" at crash sites. Readers of the *Handbook* must note that the treatments presented therein do not constitute a new standard of required practice. The final decision about when and where to apply the treatments presented in the *Handbook* remains at the discretion of State and local design and engineering professionals.

This paper highlights treatments particularly applicable to the urban street environment that are contained within the *Handbook* and the accompanying *Desk Reference* to the *Handbook*. Unless otherwise specified, the use of the word "aging" in this paper is based on the context of the word as used in the *Handbook* and refers to persons that are at least 65 years of age.

INTERSECTIONS

The single greatest concern in accommodating aging road users, both drivers and pedestrians, is the ability of these persons to negotiate intersections safely. For at least two decades, safety experts have keyed on relationships of age and road user type (driver or pedestrian) to understand injury and fatal crash experience at intersections in the United States. The findings of one widely cited analysis of nationwide crash data (*7*) are shown in FIGURE 2, which illustrates that aging drivers and pedestrians are involved in a higher percentage of injury and fatal crashes at intersections. Similar trends can be found in the data to the present day. Thus, it is important to identify treatments that can serve as meaningful countermeasures to the problems faced by aging road users at intersections. Chapter 2 of the *Handbook* contains 16 proven practices and eight promising practices for intersections, including most of the *Handbook*'s treatments that are commonly applicable to urban streets. This section of this paper contains summaries of selected treatments from the *Handbook* that can be applied to urban intersections. The full set of treatments can be found in Part I of the *Handbook*, and the supporting information on which the *Handbook*'s recommendations are made can be found in Part II.

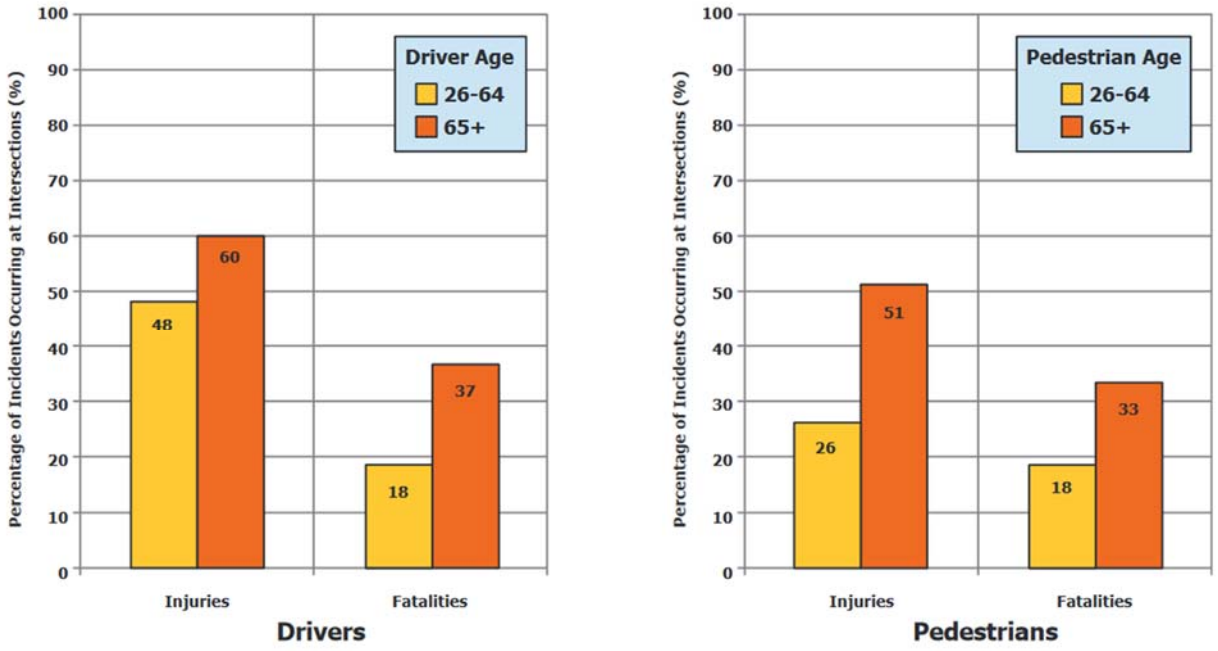
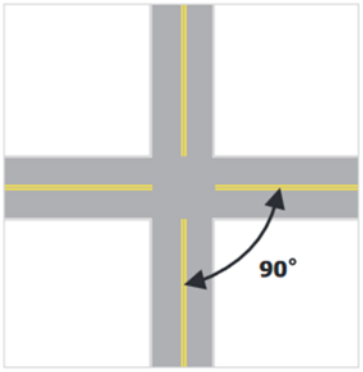


FIGURE 2 Percent of crashes involving drivers and pedestrians by age at intersections. (*5*)

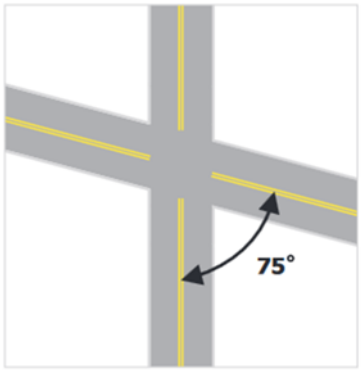
Intersecting Angle (Skew)

The *Highway Safety Manual* (HSM) (*8*) defines skew angle as: "intersection skew angle (in degrees); the absolute value of the difference between 90 degrees and the actual intersection angle. Right-angle intersections are broadly accepted as the preferred design. Decreasing the angle makes detection of and judgments about potential conflicting vehicles on crossing roadways much more difficult. In addition, the amount of time required to travel through the intersection increases, for both vehicles and pedestrians, due to the increased pavement area. Skewed intersections pose particular problems for aging drivers. Many aging drivers experience a decline in head and neck mobility, which accompanies advancing age and may contribute to the slowing of psychomotor responses. This obviously creates more of a problem in determining appropriate gaps. For aging pedestrians, the longer exposure time within the intersection becomes a major concern.

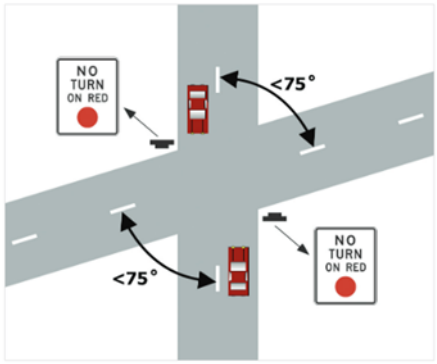
The *Handbook* recommends that in the design of new facilities or redesign of existing facilities where right-of-way is not restricted, all intersecting roadways should meet at a 90-degree angle (as indicated in FIGURE 3a). In the design of new facilities or redesign of existing facilities where right-of-way is restricted, intersecting roadways should meet at an angle of not less than 75 degrees (as indicated in FIGURE 3b). At skewed signalized intersections where the approach leg to the left intersects the driver's approach leg at an angle of less than 75 degrees, right turn on red (RTOR) should be prohibited (see FIGURE 3c).



(a) Example 90° angle of intersection



(b) Example 75° angle of intersection



(c) Skewed signalized intersection with prohibition of right turn on red

FIGURE 3 Illustrations of skew angle at intersections. (*5*)

Channelization

Raised channelization with sloping curbs is recommended over channelization accomplished through the use of pavement markings alone (flush) for left- and right-turn lane treatments at intersections on all roadways with operating speeds of less than 45 mph. Where raised channelization is implemented at intersections the median and island curb sides and curb horizontal surfaces should be treated with retroreflectorized markings, such as edge lines, painted curbs, or raised pavement markers, and be maintained at a minimum luminance contrast level of at least 2.0 with overhead lighting or at least 3.0 without overhead lighting. Contrast should be calculated according to this formula:

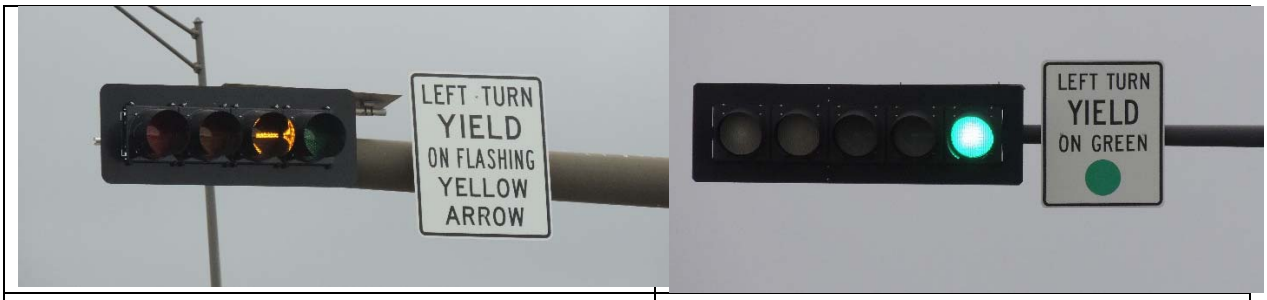
$$\text{Luminance contrast (C)} = \frac{\text{Luminance}_{\text{stripe}} - \text{Luminance}_{\text{pavement}}}{\text{Luminance}_{\text{pavement}}}$$

If right-turn channelization is present and pedestrian traffic may be expected based on surrounding land use, it is recommended that an adjacent pedestrian refuge island, conforming to MUTCD (*9*) and AASHTO *Green Book* (*10*) specifications, be provided. The use of sloping curbs rather than vertical curbs is recommended, except where the curbs surround a pedestrian refuge area or are being used for access control. To reduce unexpected midblock conflicts with opposing vehicles, the use of channelized left-turn lanes in combination with continuous raised-curb medians is recommended instead of center, two-way, left-turn lanes (TWLTL) for new construction or reconstruction where average daily traffic volumes exceed 20,000 vehicles per day, or for remediation where there is a demonstrated crash problem, or wherever a need is demonstrated through engineering study.

Left-Turn Traffic Control for Signalized Intersections

The use of protected-only left-turn operations is recommended for all left-turning movements, whenever appropriate. In particular, protected-only left-turn phasing should be considered where minimum intersection sight distance requirements are not achieved through the use of offset left-turn lanes or other geometric design features, or where a pattern of permissive left-turn crashes occurs. The flashing yellow arrow (see FIGURE 4a) is the recommended signal indication for

permissive left-turn movements at signalized intersections. If circular green (see FIGURE 4b) is used as the permissive indication of a protected/permissive left-turn, consistent use of the MUTCD R10-12 sign, (LEFT TURN YIELD ON GREEN) is recommended, with overhead placement adjacent to the left-turn signal face (see Figure 13).



(a) Flashing yellow arrow permissive left-turn signal	(b) Circular green permissive left-turn signal

FIGURE 4 Illustrations of permissive left-turn signal indications.

Right-Turn Traffic Control for Signalized Intersections

At signalized intersections where a right turn on red is prohibited, a supplemental NO TURN ON RED sign, using the MUTCD R10-11 design as shown in FIGURE 3c, should be placed at a location on either the near or opposite side of the intersection where, per engineering judgment, it will be most conspicuous. This supplemental NO TURN ON RED sign is in addition to the MUTCD recommended practice of installing an R10-11 series sign near the appropriate signal head. The posting of MUTCD standard R10-15 signs, Turning Vehicles Yield to Pedestrians (shown in FIGURE 5) is recommended wherever engineering judgment indicates a clear potential for right-turning vehicles to come into conflict with crossing pedestrians.

FIGURE 5 Turning Vehicles Yield to Pedestrians (R10-15) Sign. (*9*)

Lane Assignment on Intersection Approach

The consistent overhead placement of lane-use control signs (MUTCD R3-5 and R3-6 series) at intersections on a signal mast arm or span wire is recommended, as illustrated in FIGURE 6. The consistent posting of lane-use control signs plus application of lane-use arrow pavement markings at a preview distance of at least 5 s (at operating speed) in advance of a signalized

intersection is recommended, regardless of the specific lighting, channelization, or delineation treatments implemented at the intersection. R3-5 and R3-6 series signs should be mounted overhead wherever practical.

FIGURE 6 Mast-arm mounted lane-use control signs. (*5*)

Traffic Signals

Backplates with retroreflective borders should be considered as part of efforts to systematically improve safety performance at signalized intersections. The use of backplates with signals is recommended on roads with operating speeds lower than 40 mph where engineering judgment indicates a need due to the potential for sun glare problems, site history, or other variables. Yellow retroreflective borders, shown in FIGURE 7, may be used as an option to improve visibility of the illuminated face of the signal. The yellow retroreflective strip should have a minimum width of 1 inch and a maximum width of 3 inches and be placed along the perimeter of the face of a signal backplate to project a rectangular appearance at night.

FIGURE 7 Yellow retroreflective backplates. (*5*)

Pedestrian Crossings

To accommodate the aging pedestrian who typically has a shorter stride, slower gait, and delayed "start-up" time before leaving from a position further back from the curb at signalized crossings, the joint application of the following practices is recommended:

- Use a walking speed of 3.0 ft/s to calculate total crossing time (WALK interval plus pedestrian clearance interval).
- Measure crossing distance from a location 6 ft back from the curb or travel lane edge to the far side of the travel way being crossed.

For pedestrian crossings where the right-turn lane is channelized, it is recommended that:

- An adjacent pedestrian refuge island conforming to MUTCD (*9*) and AASHTO (*10*) specifications be provided.
- If a crosswalk is within the channelized area, it should be located approximately one car length from the yield line for the intersection (see FIGURE 8), which will allow drivers on the approach leg to look for and yield to pedestrians before reaching the intersecting roadway and scanning for gaps in traffic.

At intersections with high turning-vehicle volumes and no turn on red (NTOR) control for traffic moving parallel to a marked crosswalk, a leading pedestrian interval (LPI), timed to allow slower walkers to cross at least one moving lane of traffic is recommended to reduce conflicts between pedestrians and turning vehicles. The length of the LPI, which should be at least 3 s, may be calculated using the formula:

$$LPI = (ML + PL + 6.0)/3.0$$

where:

LPI = seconds between onset of the WALK signal for pedestrians and the green indicator for vehicles.
ML = width of moving lane in ft
PL = width of parking lane (if any) in ft
6.0 = distance in ft back from the edge of the curb to the assumed starting location for pedestrians
3.0 = walking speed in ft/s

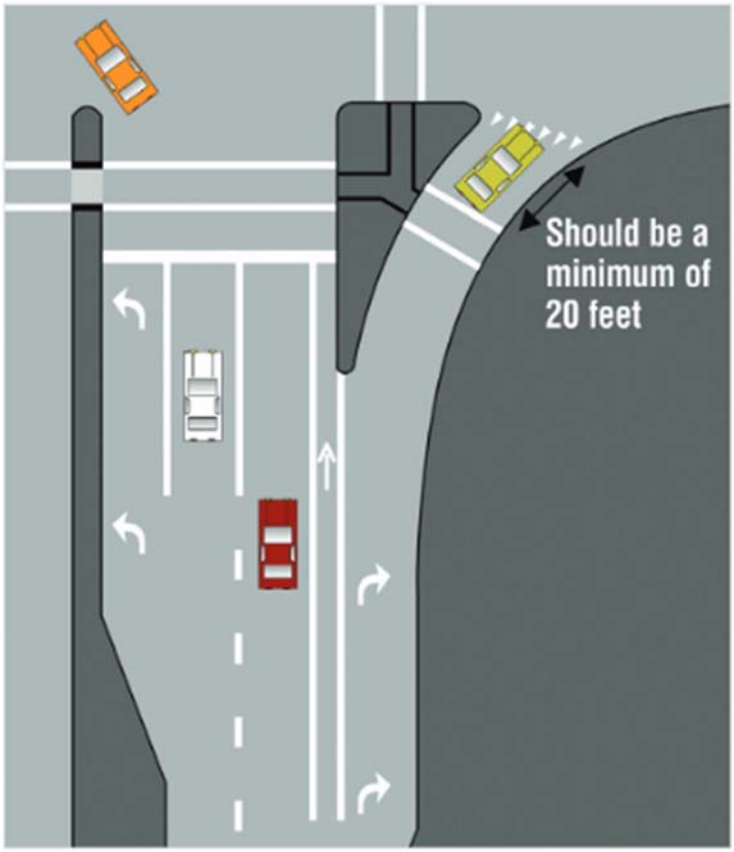


FIGURE 8 Pedestrian crossing at channelized right-turn lane. (*5*)

Countdown pedestrian signals (see Figure 28) should be installed at all signalized intersections where pedestrian signals are warranted. The 2009 MUTCD (*9*) requires the use of countdown pedestrian signals when the pedestrian change interval is greater than 7s.

Right-Turn Channelization Design

The guidance for this promising practice states that right-turn channelization with tighter turning radii to reduce turning speeds to approximately 17 to 18 mph, decrease pedestrian crossing distances, and optimize the right-turning motorists' line of sight should be considered during design, as shown in the Preferred example on the right of FIGURE 9. Designs such as those on the left of FIGURE 9 are potentially problematic as drivers have to turn their heads farther to see oncoming traffic. The short curve radius should be between 25 and 40 ft, and the long curve radius should be between 150 and 275 ft. Traffic control devices at the end of the channelization should be visible to vehicles entering the channelized lane.

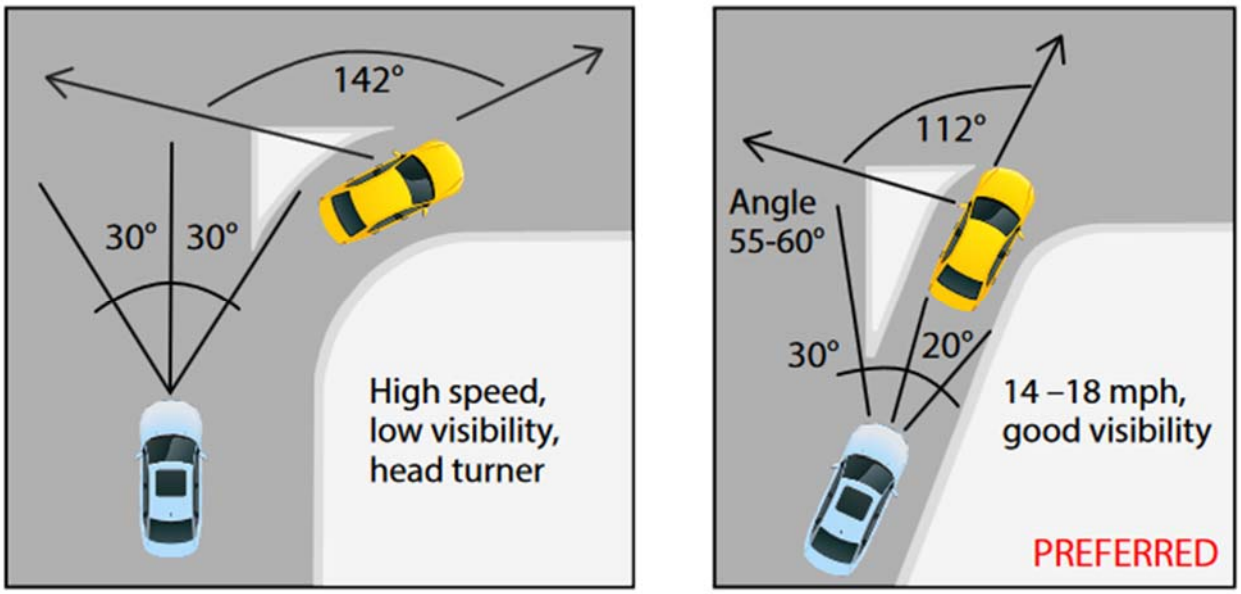


FIGURE 9 Right-turn channelization design. (*5*)

High-Visibility Crosswalks

To allow drivers to more easily see pedestrians in a marked crosswalk, high-visibility crosswalk marking patterns should be used. Two examples of such markings include white diagonal lines at a 45-degree angle to the crosswalk or the "ladder" crosswalk design shown in FIGURE 10.

FIGURE 10 High-visibility ("ladder") crosswalk. (*5*)

Accessible Pedestrian Signal (APS) Treatments

At crosswalks frequently used by aging pedestrians, consider inclusion of pushbutton-activated extension of the pedestrian crossing phase, using the required signage described by the MUTCD, as shown in FIGURE 11. Use of passive pedestrian detection to help aging pedestrians who have difficulty using the pushbutton or to detect pedestrians within the crosswalk that may need more time to complete the crossing maneuver. Passive pedestrian detection uses sensors to detect the presence of pedestrians and register a pedestrian call with the signal system; as a result, the pedestrian does not have to push a button to request a WALK signal or extended crossing time.

FIGURE 11 Extended crossing time (R10-32P) sign. (*9*)

OTHER LOCATIONS

Chapters 3 through 6 of the Handbook discuss recommendations for treatments at non-intersection locations: interchanges, roadway segments, construction/work zones, and highway-rail grade crossings. This section of the paper will highlight treatments from these categories that are applicable to urban streets.

Freeway Entrance Traffic Control Devices / Restricted and Wrong-Way Movements

A 48-in × 30-in guide sign panel with the legend Freeway Entrance (see FIGURE 12), using a minimum letter height of 8 inches, should be consistently used in situations where freeway entrance and exit ramps are adjacent to one another (such as at a partial cloverleaf interchange) and placed as described in Section 2D.46 and shown in Figure 2D-14 of the MUTCD (*9*).

FIGURE 12 Freeway Entrance (D13-3) sign. (*9*)

Where adjacent entrance and exit ramps intersect with a crossroad, the use of a median separator, either painted or preferably raised, is recommended, with the nose of the separator delineated with yellow retroreflectorized markings and extending as close to the crossroad as

practical without obstructing the turning path of vehicles (see FIGURE 13). Where engineering judgment determines the need for the median nose to be set back from the intersection, the setback distance should be treated by a 12-in or wider yellow stripe. In addition, a KEEP RIGHT (R4-7) sign should be posted on the median separator nose, if it is raised.

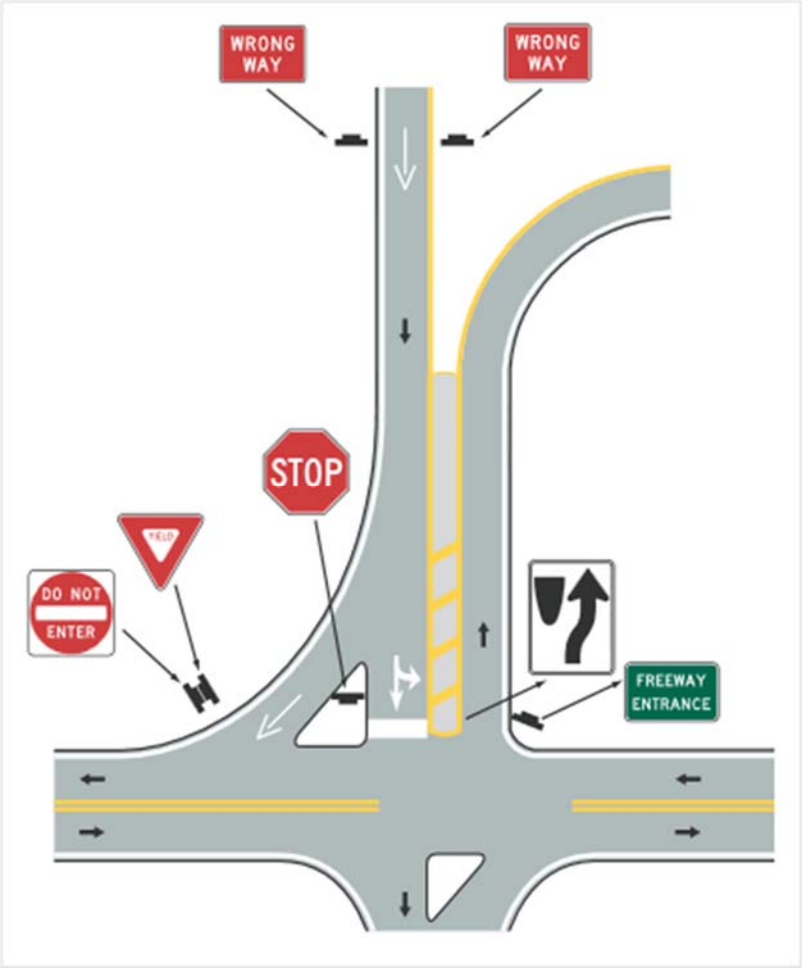


FIGURE 13 Recommended signs and markings for adjacent entrance/exit ramps at a crossroad intersection. (*5*)

To meet overriding concerns for enhanced conspicuity of signing for prohibited movements, the following countermeasures should be used where DO NOT ENTER (R5-1) and WRONG WAY (R5-1a) signs are used:

- For enhanced conspicuity of DO NOT ENTER (R5-1) and WRONG WAY (R5-1a) signs placed on freeway ramps, use larger than minimum MUTCD sizes for freeway applications with corresponding increases in letter size.
- To provide increased sign conspicuity and legibility for aging drivers, use retroreflective fluorescent red sheeting materials that provide for high retroreflectance overall.
- Where engineering judgment indicates an exaggerated risk of wrong-way movement crashes, both the R5-1 and R5-1a signs should be installed on both sides of the ramp, placed in accordance with the MUTCD.

- Where all other engineering options have been tried or considered, lowering sign height to maximize brightness under low-beam headlight illumination is recommended by mounting the signs 36 in above the pavement (measured from the road surface to the bottom of the sign), or the lowest value above 36 in that is practical when the presence of snow, vegetation, or other obstructions is taken into consideration.

The *Handbook* also makes two recommendations for pavement markings to minimize occurrences of restricted or wrong-way movements:

- The application of 23.5-ft long wrong-way arrow pavement markings near the terminus on all exit ramps is recommended.
- Where engineering judgment indicates a need for increased conspicuity, wrong-way arrow pavement markings should be supplemented with red/white bidirectional retroreflective raised pavement markers.

The NTSB's FARS analysis determined that drivers over the age of 70 are over-represented in fatal wrong-way crashes (*11*). Additional treatments to counter wrong-way driving by aging drivers (e.g., improved lighting, channelization, signs and markings in addition to those in Treatment 30) should be considered where exit ramps intersect with surface streets. Road owners could employ the use of a Road Safety Audit (RSA) to examine the performance of the interchange and determine appropriate countermeasures to employ. A Wrong-Way Driving (WWD) Prompt list is available to focus specific attention on wrong-way driving issues and contributing factors. The prompt list has been developed in a similar framework to the broader RSA prompt lists contained in Chapter 8 of the FHWA RSA Guidelines document. The prompts are only an aid to the RSA team and they are not intended to cover all conditions or circumstances an RSA team may encounter. The American Traffic Safety Services Association also provides a publication that describes promising practices in wrong-way driving countermeasures (*12*); a review of that document should be included during the consideration of potential WWD treatments to implement.

Vertical Curves at Intersections

If a signalized intersection is obscured by vertical curvature in a manner that the signal becomes visible at a preview distance of 8 s or less (at operating speed), then it is recommended that, in addition to the standard advance signal warning sign (MUTCD W3-3), a BE PREPARED TO STOP warning sign (MUTCD W3-4) and WHEN FLASHING plaque (MUTCD W16-13) be used along with a warning beacon interconnected with the traffic signal controller (see FIGURE 14). The yellow warning beacon should be activated at a sufficient interval prior to the onset of the yellow signal phase and sustained after the onset of the green signal phase to take into account the end of queues experienced during peak traffic conditions, as determined through engineering study.

FIGURE 14 Be Prepared to Stop (W3-4) sign and When Flashing (W16-13) plaque with beacons. (*9*)

Portable Changeable Message Signs in Work Zones

The MUTCD (*9*) requires that no more than two phases be used on a changeable message sign (CMS). If a message cannot be conveyed in two phases, multiple CMSs and/or a supplemental highway advisory radio message should be used; alternatively, the action statement only may be presented on a single page/phase. Each phase of a CMS message should be displayed for a minimum of 3 s.

It is recommended that no more than one unit of information be displayed on a single line on a CMS, and no more than three units should be displayed for any single phase. A unit of information is one or more words that answers a specific question (e.g., What happened? Where? What is the effect on traffic? What should the driver do?). For CMS messages split into two phases, a total of no more than four unique units of information should be presented.

When a CMS is used to display a message in two phases, the problem and location statements should be displayed during phase 1 and the effect or action statement during phase 2. If legibility distance restrictions rule out a two-phase display, the use of abbreviations (as specified in the MUTCD) plus elimination of the problem statement is the recommended strategy to allow for the presentation of the entire message in one phase.

For superior legibility, only single-stroke lettering should be used for displays of alphanumeric characters on portable CMSs with the conventional 5- x 7-pixel matrix; double-stroke lettering should be avoided. As new portable CMSs are procured by a highway agency, the performance specifications of such devices should include a minimum character width-to-height ratio of 0.7 (complete character) and a maximum stroke width-to-height ratio of 0.13. Portable changeable message signs should be elevated to a height sufficient to be seen across multiple lanes of (same-direction) traffic by approaching passenger car drivers.

CONCLUSION

The FHWA *Handbook for Designing Roadways for the Aging Population* contains recommendations on 51 proven practices and promising practices, many of which are applicable to urban street environments. Highlights of some of those treatments have been summarized in this paper to encourage engineers, planners, and other practitioners to consider them in locations that currently have a sizeable proportion of older road users or are expected to have such a proportion of these users within the life of the project under consideration. Full details of each of

these treatments can be found within the *Handbook* (*5*) and the corresponding Desk Reference (*6*), and practitioners are encouraged to consult those documents for complete information, or contact FHWA (*13*) with any questions related to treatments for older road users.

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