FHWA Guidelines for Older Drivers and Pedestrians

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Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians

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FOREWORD

The proportion of the population over age 65 is growing significantly. Older road users can be expected to have problems as drivers and as pedestrians, given the known changes in their perceptual, cognitive, and psychomotor performances. This situation presents many challenges to transportation engineers, who must ensure system safety while increasing operational efficiency.

This Guidelines and Recommendations document provides practitioners with a condensed source of practical information that links older road user characteristics to highway design, operational, and traffic engineering recommendations by addressing specific roadway features. These Guidelines and Recommendations supplement existing standards and guidelines in the areas of highway geometry, operations, and traffic control devices.

The information in this document should be of interest to highway designers, traffic engineers, and highway safety specialists involved in the design and operation of highway facilities. In addition, this document will be of interest to researchers concerned with issues of older road user safety and mobility. The rationale and supporting evidence used to develop these recommendations, summarizing more than three decades of highway safety research, is contained in the *Highway Design Handbook for Older Drivers and Pedestrians*, FHWA-RD-01-103

Copies of this report can be obtained through the FHWA Research and Technology Report Center, 9701 Philadelphia Court, Unit Q, Lanham, Maryland 20706, telephone: (301) 577-0818, fax: (301) 577-1421, or the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia, 22161, telephone: (703) 487-4650, fax: (703) 321-8547.

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Research and Development

NOTICE

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16. Abstract

This project updated, revised, and expanded the scope of the *Older Driver Highway Design Handbook* published by the Federal Highway Administration (FHWA) in 1998. Development of the updated Handbook (FHWA-RD-01-103) was complemented by a technology transfer initiative to make practitioners aware of the Handbook and assist in applying its recommendations. This effort included the development of a condensed document presenting recommendations and implementation guidelines only, plus printed and electronic materials supporting the conduct of practitioner workshops throughout the United States in the 1999-2001 period.

Consistent with the full Handbook, this Guidelines and Recommendations document incorporates new research findings and technical developments and extensive feedback from State, county, and municipal engineers who reviewed and applied recommendations from the 1998 publication. Guidance on how and when to implement the included recommendations is included, as well as codes that indicate at a glance the relationship of each recommendation to standard design manuals, including the *Manual on Uniform Traffic Control Devices* and the American Association of State Highway and Transportation Officials *Green Book*.

All research products developed under this contract are designed to provide practical guidance to engineers to accommodate the needs and functional limitations of an aging population of road users. Included recommendations are directed toward new construction, reconstruction, scheduled maintenance, and “spot treatments” to ameliorate demonstrated safety problems, emphasizing countermeasures with modest additional cost during installation and the potential for cost savings over the life cycle.

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Unclassified	Unclassified	86	

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3

NOTE: Volumes greater than 1000 l shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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INTRODUCTION

The increasing number and percentage of older drivers using the Nation's highways in the decades ahead will pose many challenges to transportation engineers, who must ensure system safety while increasing operational efficiency. The 65 and older age group, which numbered 34.7 million in the United States in 2000, will grow to more than 36 million by 2005 and will exceed 50 million by 2020, accounting for roughly one-fifth of the population of driving age in this country. In effect, if design is controlled by even 85th percentile performance requirements, the "design driver" of the early 21st century will be an individual over the age of 65.

In 1998, FHWA published the *Older Driver Highway Design Handbook*, seeking to provide highway designers and engineers with a practical information source linking the declining functional capabilities of older road users to the need for design, operational, and traffic engineering enhancements keyed to specific roadway features. Early experiences with the recommendations, including extensive feedback from local- and State-level practitioners through workshops conducted for departments of transportation (DOT's) across the country in 1999 and 2000, indicated a need to revise and update this resource. The result is the *Highway Design Handbook for Older Drivers and Pedestrians*. Recent research has been incorporated, format and content changes have been made to improve its usefulness, guidance on how to implement its recommendations has been added, and the range of applications covered by the Handbook has been expanded.

This document contains the updated recommendations and information on how to apply the Handbook. These are excerpted from the full report (FHWA-RD-01-103), which also includes a detailed discussion of the rationale and supporting evidence for each recommendation. At the end of this document, supplemental technical notes not found in the full Handbook are provided to explain (1) how specific diminished capabilities lead to age-related driving problems; (2) license renewal requirements and distinctions for older drivers in each State in the U.S.; and (3) how and why to conduct visibility measurements to ensure that various pavement marking treatments covered in this Handbook serve the needs of older road users. These materials are included to support practitioners in exercising the engineering judgment often called upon to reach implementation decisions.

The recommendations in the Handbook do not constitute a new standard of required practice, but instead are intended to supplement existing standards and guidelines in the areas of highway geometry, operations, and traffic control devices to proactively respond to the changing demands on the Nation's roadway facilities. The recommendations provide guidance that is firmly grounded in an understanding of older drivers' and pedestrians' needs and capabilities, and can significantly enhance the safety and ease of use of the highway system for older persons, and for the driving population as a whole.

HOW TO USE THIS HANDBOOK

RELATING RECOMMENDATIONS TO STANDARD DESIGN GUIDES

Codes placed outside and to the left of each recommendation in this Handbook indicate its relationship to the design guides most frequently referenced by practitioners, as determined by the Handbook authors. An example is shown below.

Recommendations by Design Element

A. Design Element: Intersecting Angle (Skew)

AASHTO:1
ICG:1
ITE:1

(1) 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.

Relationship codes 1 through 4, plus a fifth code (IEC), are defined as follows:

1 Handbook recommendation selects the most conservative design value among present options in the standard manual/guideline. (*Example*: Using a larger sign size identified as an "option" in the *MUTCD*).

2 Handbook recommendation indicates the preferred design value where a discrepancy exists between current standards/guidelines. (*Example*: Limit skew to 75° as per ITE instead of 60° as per AASHTO).

3 Handbook recommendation extends a current practice to a new application or operation. (*Example*: Use of fluorescent sheeting on wrong-way control signing, for increased conspicuity).

4 Handbook recommendation advances a specific design value where only general guidance now exists, or provides more detailed or more stringent design criteria than are currently specified. (*Example*: Assume 0.4 m of visibility per mm [33 ft per inch] of letter height on highway signing, not 0.6 m/mm [50 ft/in] as in *MUTCD* 1988, or even 0.5 m/mm [40 ft/in] as proposed for *MUTCD* 2000).

IEC Handbook recommendation is permissible at this time only in accordance with the provisions of *MUTCD* section 1A.10, *Interpretations, Experimentations, and Changes*.

These recommendations represent advances in technology that research indicates will result in improved safety and efficiency of operations.

The standard design guides referenced by the relationship codes in the example above and throughout the Handbook are listed below. The most current published edition of each guide was consulted in the preparation of the Handbook, with the exceptions as noted.

AASHTO	*A Policy on Geometric Design of Highways and Streets*. American Association of State Highway and Transportation Officials, 1994.
HCM	*Highway Capacity Manual*. Transportation Research Board, 1999. (Special Report 209)
ICG	*Intersection Channelization Design Guide*. National Cooperative Highway Research Program, 1985. (Report No. 279)
ITE	*Traffic Engineering Handbook*. Institute of Transportation Engineers, 1999.
MUTCD	*Manual on Uniform Traffic Control Devices for Streets and Highways*. Federal Highway Administration, 2000.
RLH	*Roadway Lighting Handbook*. Federal Highway Administration, 1978. Implementation Package 78-15. (Reprinted April 1984) [NOTE: Although an Addendum to Chapter Six of the *Roadway Lighting Handbook* was produced in 1983, the recommendations pertaining to the *RLH* primarily reference material found in the chapters produced in the 1978 version.]
RND	*Roundabouts: An Informational Guide*. Federal Highway Administration, 2000.
RRX	*Railroad-Highway Grade Crossing Handbook*. Federal Highway Administration, 1986.

INTERPRETING HANDBOOK GRAPHICS

The included figures and drawings are for illustrative purposes only, to clarify the meaning of a recommendation or to show what design was employed in a research study referenced in the Rationale and Supporting Evidence section. It is important to note that the fonts and arrow graphics used in this Handbook are not always consistent with the *MUTCD*-approved fonts and arrows. When employing recommendations included in this Handbook, only *MUTCD*-approved fonts and arrow graphics should be used.

USING THE TIME-SPEED-DISTANCE TABLE

A number of recommendations presented in the Handbook identify the placement of a device or treatment in terms of the preview time that should be provided to the driver for its application. These values are typically expressed in seconds, such that the recommended placement of the device or treatment depends upon the speed at which traffic is moving. To facilitate application of Handbook recommendations of this nature, a look-up table on the next page provides the advance placement distance needed to achieve a desired preview time at a particular operating speed.

Advance Placement Distances Required to Achieve Desired Preview Times at Designated Operating Speeds

Preview Time (seconds)	Operating Speed										
	48 km/h (30 mi/h)	**56 km/h (35 mi/h)**	**64 km/h (40 mi/h)**	**72 km/h (45 mi/h)**	**80 km/h (50 mi/h)**	**88 km/h (55 mi/h)**	**97 km/h (60 mi/h)**	**105 km/h (65 mi/h)**	**113 km/h (70 mi/h)**	**121 km/h (75 mi/h)**	**129 km/h (80 mi/h)**
2.5	34 m (110 ft)	39 m (128 ft)	45 m (147 ft)	50 m (165 ft)	56 m (183 ft)	62 m (202 ft)	67 m (220 ft)	73 m (238 ft)	78 m (257 ft)	84 m (275 ft)	89 m (293 ft)
3.0	40 m (132 ft)	47 m (154 ft)	54 m (176 ft)	60 m (198 ft)	67 m (220 ft)	74 m (242 ft)	81 m (264 ft)	87 m (286 ft)	94 m (308 ft)	101 m (330 ft)	107 m (352 ft)
3.5	47 m (154 ft)	55 m (180 ft)	63 m (205 ft)	70 m (231 ft)	78 m (257 ft)	86 m (282 ft)	94 m (308 ft)	102 m (334 ft)	110 m (359 ft)	117 m (385 ft)	125 m (411 ft)
4.0	54 m (176 ft)	63 m (205 ft)	72 m (235 ft)	81 m (264 ft)	89 m (293 ft)	98 m (323 ft)	107 m (352 ft)	116 m (381 ft)	125 m (411 ft)	134 m (440 ft)	143 m (469 ft)
4.5	60 m (198 ft)	70 m (231 ft)	81 m (264 ft)	91 m (297 ft)	101 m (330 ft)	111 m (363 ft)	121 m (396 ft)	131 m (429 ft)	141 m (462 ft)	151 m (495 ft)	161 m (528 ft)
5.0	67 m (220 ft)	78 m (257 ft)	89 m (293 ft)	101 m (330 ft)	112 m (367 ft)	123 m (403 ft)	134 m (440 ft)	145 m (477 ft)	157 m (513 ft)	168 m (550 ft)	179 m (587 ft)
5.5	74 m (242 ft)	86 m (282 ft)	98 m (323 ft)	111 m (363 ft)	123 m (403 ft)	135 m (444 ft)	148 m (484 ft)	160 m (524 ft)	172 m (565 ft)	185 m (605 ft)	197 m (645 ft)
6.0	81 m (264 ft)	94 m (308 ft)	107 m (352 ft)	121 m (396 ft)	134 m (440 ft)	148 m (484 ft)	161 m (528 ft)	174 m (572 ft)	188 m (616 ft)	201 m (660 ft)	215 m (704 ft)
6.5	87 m (286 ft)	102 m (334 ft)	116 m (381 ft)	131 m (429 ft)	145 m (477 ft)	160 m (524 ft)	174 m (572 ft)	189 m (620 ft)	204 m (667 ft)	218 m (715 ft)	233 m (763 ft)
7.0	94 m (308 ft)	110 m (359 ft)	125 m (411 ft)	141 m (462 ft)	157 m (513 ft)	172 m (565 ft)	188 m (616 ft)	204 m (667 ft)	219 m (719 ft)	235 m (770 ft)	250 m (822 ft)
7.5	101 m (330 ft)	117 m (385 ft)	134 m (440 ft)	151 m (495 ft)	168 m (550 ft)	185 m (605 ft)	201 m (660 ft)	218 m (715 ft)	235 m (770 ft)	252 m (825 ft)	268 m (880 ft)
8.0	107 m (352 ft)	125 m (411 ft)	143 m (469 ft)	161 m (528 ft)	179 m (587 ft)	197 m (645 ft)	215 m (704 ft)	233 m (763 ft)	250 m (822 ft)	268 m (880 ft)	286 m (939 ft)

KNOWING WHEN TO IMPLEMENT THESE RECOMMENDATIONS

Implementation of the recommendations in this Handbook is expected to provide remedies for design deficiencies that disproportionately penalize older road users due to changes in functional ability experienced with normal aging. These may be most urgently needed where a crash problem with older drivers or pedestrians has already been demonstrated; however, the greater benefit arguably lies in designing safer new roads and identifying and modifying problems with existing roads before statistics reveal a crash problem. Not only does this practice minimize the risk and severity of crashes, it minimizes the need for remedial works after construction, thus reducing the whole-life cost of projects. This is the central premise of the *road safety audit* process supported by FHWA (1997) and ITE (1995), and it holds the key for applying the Handbook's recommendations as well.

The engineering enhancements described in this document should benefit all road users, not just older persons. However, if higher construction costs, the need for additional right-of-way, or other factors are present, special justification may be required for implementation of Handbook practices. This section was developed to support engineering judgment in this regard. It suggests a three-step procedure using checklist responses plus brief written comments, as explained below. A separate Implementation Worksheet for meeting the requirements of each step is also provided. It is assumed that DOT's have in place processes that define when a crash pattern or a safety problem is evident; this Handbook does not address this level of analysis. Furthermore, it is recognized that States may already follow processes that make the approach described in this section unnecessary. FHWA has no desire to interfere with any procedures used by States that take the same information into account and accomplish the same ends as the three-step procedure below.

<u>Step 1: Problem Identification</u> *[see worksheet on page 8]*

During the planning stage for each project involving new construction or reconstruction of an existing facility, practitioners are asked to determine whether a problem with the safe use of the facility by older drivers and pedestrians currently exists *or* may reasonably be expected based on current and projected use patterns. Using the first worksheet that follows this discussion, problem identification can be accomplished by checking YES or NO to the following four questions:

Q1. "Is there a demonstrated crash problem with older drivers or pedestrians?"

Q2. "Has any aspect of design or operations at the project location been associated with complaints to local, municipal, or county-level officials from older road users *or* are you aware of a potential safety problem at this location, either through personal observation or agency documentation, applying your own engineering judgment?"

Q3. "Is this project located on a direct link to a travel origin or destination for which, in the judgment of local planning/zoning authorities or other local officials, older persons constitute a significant proportion of current users?"

Q4. "Is the project located in a census tract or zip code designation that has experienced an increase in the proportion of (non-institutionalized) residents age 65 and older, for the most recent period in which the population was sampled?"

To answer these questions, practitioners will need to obtain reliable crash data from the appropriate division or bureau of their departments of transportation. At least the three most recent years for which data are available should be examined, and the data should be sorted by age, at a minimum. Sources of information outside of the State DOT also may be required to answer the problem identification questions. Potential sources include, but are not limited to:

- Local government officials/Board of Supervisors/city council representatives.
- Local and State police.
- The (State) Department of Aging and/or county Area Agency on Aging.
- The (State) Department of Health and Human Services and Department of Public Welfare.
- The regional planning commission.

Step 2: Identification of Candidate Handbook Applications *[see worksheet on page 9]*

For each project where a practitioner has answered YES to one or more of the problem identification questions in Step 1, the next step is to identify every design element at the to-be-constructed facility for which a recommendation is included in the Handbook. These recommendations should be listed. Then, for each one, the engineer should indicate whether the recommended practice differs from standard State or local practices, and if yes, what additional benefits are expected to result from implementing the applicable Handbook recommendation(s). One possible example of how such worksheet entries could be made is shown below.

Design Elements Addressed by Handbook Recommendations	Applicable Handbook Recomm.	Differs From Existing State or Local Practice?		If YES...	
		NO	YES	Explain Difference	Identify Expected Benefits
IA. Intersection Angle (Skew)	IA(3)		✔	According to MUTCD warrants, there is "adequate" sight distance and fewer than 3 RTOR crashes annually on approach.	Should reduce the difficulty for older drivers to check for approaching traffic, and also reduce aggressive behavior of following drivers who don't accept an older driver's decision not to turn on red.
IJ. Street-Name Signing	IJ(1)	✔			

Step 3: Implementation Decision *[see worksheet on page 10]*

To begin Step 3, each Handbook recommendation identified as a candidate for imple-mentation in Step 2 should be properly referenced [e.g., I.E.4(4a)]. Next, any factors relating to increased costs (for an enhanced treatment), added approvals that may be needed, or any other special considerations that impact implementation may be noted in separate columns on the worksheet. The final step is then to proceed to an implementation decision. This is recorded as a judgment by the engineer as to whether implementation of the candidate countermeasure is recommended. The engineer's judgment is indicated by a check in the space next to YES or NO in the last column on the worksheet, accompanied by his/her initials for verification. Additional comments should be entered as deemed appropriate.

STEP 1: Problem Identification/Project Review Worksheet for *Highway Design Handbook for Older Drivers and Pedestrians*

Project Title/ID:

____

Person Completing Worksheet: ___________________________ Date: ____________

Q1. "Is there a demonstrated crash problem with older drivers or pedestrians?"

NO _____

YES ____

Source(s): Date of Contact:

____ _______________

____ _______________

Q2. "Has any aspect of design or operations at the project location been associated with complaints to local, municipal, or county-level officials from older road users *or* are you aware of a potential safety problem at this location, either through personal observation or agency documentation, applying your own engineering judgment?"

NO _____

YES ____

Source(s): Date of Contact:

____ _______________

____ _______________

Q3. "Is this project located on a direct link to a travel origin or destination for which, in the judgment of local planning/zoning authorities or other local officials, older persons constitute a significant proportion of current users?"

NO _____

YES ____

Source(s): Date of Contact:

____ _______________

____ _______________

Q4. "Is the project located in a census tract or zip code designation that has experienced an increase in the proportion of (non-institutionalized) residents age 65 and older, for the most recent period in which the population was sampled?"

NO _____

YES ____

Source(s): Date of Contact:

____ _______________

____ _______________

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Implementation Worksheet for *Highway Design Handbook for Older Drivers and Pedestrians*

Project Title/ID: ____

Person Completing Worksheet: ________________________________ Date: ____________

Step 2: Identification of Candidate Handbook Applications

Identify design elements for which a recommendation exists in the Handbook and the applicable recommendations. Then, (a) describe differences between the recommendation and standard practice, and (b) list benefits expected to result from implementing the Handbook.

Design Elements Addressed by Handbook Recommendations	Applicable Handbook Recomm.	Differs From Existing State or Local Practice?		If YES...	
		NO	YES	Explain Difference	Identify Expected Benefits

Implementation Worksheet for *Highway Design Handbook for Older Drivers and Pedestrians*

Project Title/ID: ____

Person Completing Worksheet: _________________________________ Date: ______________

Step 3: Implementation Decision

List each recommendation identified as being a candidate for implementation. Document whether additional approval is needed, and whether increased costs or other special considerations may impact implementation. Based on these considerations, then decide whether or not implementation can be recommended. Check YES or NO, and add your initials to record your judgment. Add supplemental comments as deemed appropriate.

Candidate Handbook Recommendation	Implementation Considerations			Implementation Recommended?
	Added Costs?	Added Approvals?	Other	
				NO ______ Initials ________ YES ______ Comments:
				NO ______ Initials ________ YES ______ Comments:

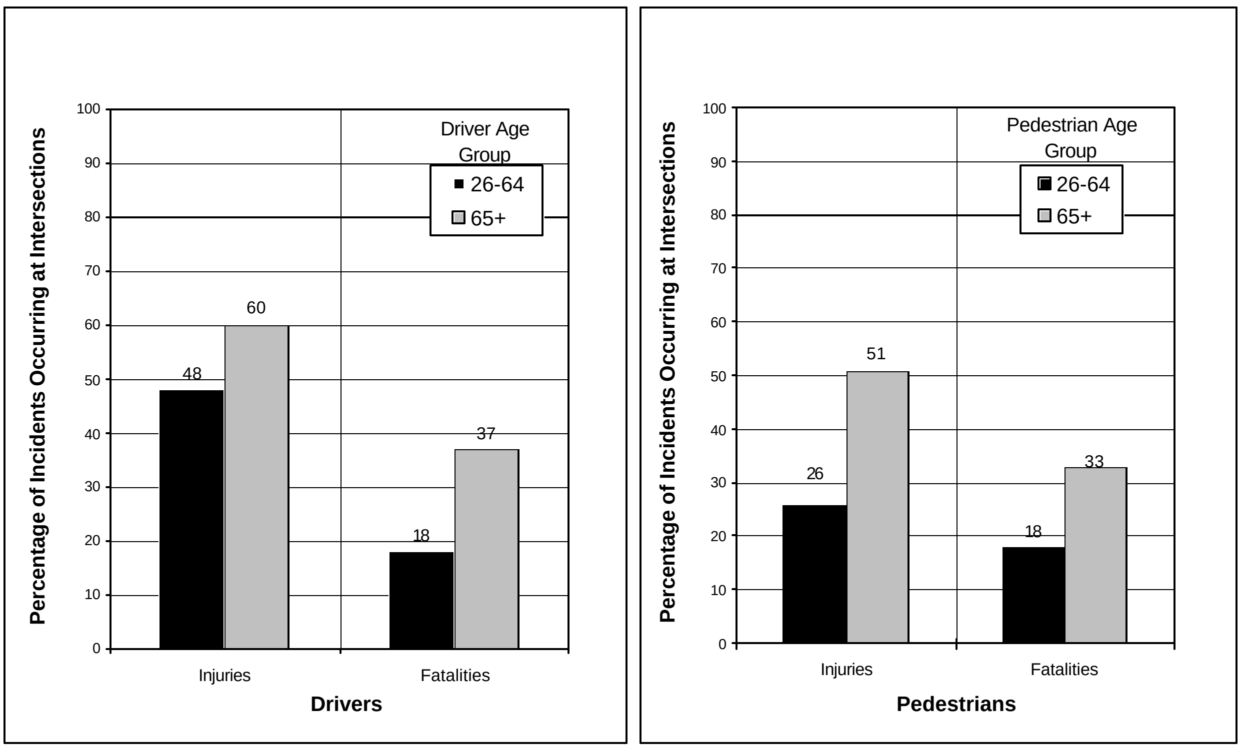
REPRODUCE THIS PAGE AS REQUIRED

RECOMMENDATIONS

I. INTERSECTIONS (AT-GRADE)

Background and Scope of Handbook Recommendations

The single greatest concern in accommodating older road users, both drivers and pedestrians, is the ability of these persons to negotiate intersections safely. The findings of one widely cited analysis of nationwide crash data (Hauer, 1988), illustrated below, reveal an enduring relationship between injuries and fatalities at intersections in the United States as a function of age and road user type (driver or



pedestrian).

For drivers 80 years of age and older, *about half* of fatal crashes occur at intersections (48 to 55 percent), compared with 23 percent or less for drivers up to 50 years of age (FARS 1998 data, in IIHS, 2000). Thirty-eight percent of pedestrian deaths among people age 65 and older in 1998 occurred at intersections (IIHS, 2000). These findings reinforce a long-standing recognition that driving situations involving complex speed-distance judgments under time constraints—the typical scenario for intersection operations—are more problematic for older drivers and pedestrians than for their younger counterparts. Other studies within the large body of evidence showing dramatic increases in intersection crash involvements as driver age increases have associated specific crash types and vehicle movements with particular age groups, linked in some cases to the driving task demands for a given maneuver (Campbell, 1993; Council and Zegeer, 1992; Staplin and Lyles, 1991).

Another approach to characterizing older driver problems at intersections was employed by Brainin (1980), who used in-car observations of driving behavior with 17 drivers ages 25–44, 81 drivers ages 60–69, and 18 drivers age 70 and older, on a standardized test route. The two older age groups showed more difficulty making right and left turns at intersections and responding to traffic signals. The left-turn problems resulted from a lack of sufficient caution and poor positioning on the road during the turn. Right-turn difficulties were primarily a result of failing to signal. Older drivers also displayed difficulty during their approach to an intersection. Errors demonstrated at STOP signs included failing to make complete stops, poor vehicle positioning at STOP signs, and jerky and abrupt stops. Errors demonstrated at traffic signals included stops that were either jerky and abrupt, failure to stop when required, and failure to show sufficient caution during the intersection approach.

Complementing crash analyses and observational studies with subjective reports of intersection driving difficulties, a statewide survey of 664 senior drivers by Benekohal, Resende, Shim, Michaels, and Weeks (1992) found that the following activities become more difficult for drivers as they grow older (with proportion of drivers responding in parentheses):

- Reading street signs in town (27 percent).
- Driving across an intersection (21 percent).
- Finding the beginning of a left-turn lane at an intersection (20 percent).
- Making a left turn at an intersection (19 percent).
- Following pavement markings (17 percent).
- Responding to traffic signals (12 percent).

Benekohal et al. (1992) also found that the following highway features become more important to drivers as they age (with proportion of drivers responding in parentheses):

- Lighting at intersections (62 percent).
- Pavement markings at intersections (57 percent).
- Number of left-turn lanes at an intersection (55 percent).
- Width of travel lanes (51 percent).
- Concrete lane guides (raised channelization) for turns at intersections (47 percent).
- Size of traffic signals at intersections (42 percent).

Comparisons of responses from drivers ages 66–68 versus those age 77 and older showed that the older group had more difficulty following pavement markings, finding the beginning of the left-turn lane, and driving across intersections. Similarly, the level of difficulty for reading street signs and making left turns at intersections increased with increasing senior driver age. Turning left at intersections was perceived as a complex driving task. This was made more difficult when raised channelization providing visual cues was absent, and only pavement markings designated which were through lanes versus turning lanes ahead. For the oldest age group, pavement markings at intersections were the most important item, followed by the number of left-turn lanes, concrete guides, and intersection lighting. A study of older road users completed in 1996 provides evidence that the single most challenging aspect of intersection negotiation for this group is performing left turns during the permitted (steady circular green indication) signal phase (Staplin, Harkey, Lococo, and Tarawneh, 1997).

During focus group discussions (Benekohal et al., 1992), older drivers reported that intersections with too many islands are confusing; raised curbs that are unpainted (unmarked) are difficult to see; and textured pavements (rumble strips) are of value as a warning of upcoming raised medians, approaches to (hidden or flashing red) signals, and the roadway edge/shoulder lane boundary. Study subjects indicated a clear preference for turning left on a protected arrow phase, rather than making permitted-phase turns. When turning during a permitted phase of signal operation, they reported waiting for a large gap before making a turn, which frustrates drivers in back of them. A key finding was the need for more time to react.

Additional insight into the problems older drivers experience at intersections was provided by focus group responses from 81 older drivers (Staplin et al., 1997). The most commonly reported problems are listed below:

- Difficulty in turning their heads at skewed (non-90-degree) angles to view intersecting traffic.
- Difficulty in smoothly performing turning movements at tight corners.
- Hitting raised concrete barriers such as channelizing islands in the rain and at night.
- Finding oneself positioned in the wrong lane—especially a "turn only" lane—during an intersection approach, due to poor visibility (maintenance) of pavement markings or the obstruction of roadside signs designed to inform drivers of intersection traffic patterns.
- Difficulty at the end of an auxiliary (right) turn lane in seeing potential conflicts well and quickly enough to smoothly merge with adjacent-lane traffic.
- Merging with adjacent-lane traffic at a pavement width reduction, when the lane drop occurs near (i.e., within 150 m [500 ft]) an intersection.

Finally, the analysis by Council and Zegeer (1992) included an examination of vehicle-pedestrian crashes and the collision types in which older pedestrians were overinvolved. The results showed older pedestrians to be overrepresented in both right- and left-turn crashes. The young-elderly (ages 65–74) were most likely to be struck by a vehicle turning right, whereas the old-elderly (age 75 and older) were more likely to be struck by a left-turning vehicle.

This section will provide recommendations for 17 different design elements in order to accommodate the needs and enhance the performance of road users with age-related diminished capabilities as they approach and negotiate intersections: A. intersecting angle (skew); B. receiving lane (throat) width for turning operations; C. channelization; D. intersection sight-distance requirements; E. offset (single) left-turn lane geometry, signing, and delineation; F. edge treatments/delineation of curbs, medians, and obstacles; G. curb radius; H. traffic control for left-turn movements at signalized intersections; I. traffic control for right-turn/right-turn-on-red (RTOR) movements at signalized intersections; J. street-name signing; K. one-way/wrong-way signing; L. stop- and yield-controlled intersection signing; M. devices for lane assignment on intersection approach; N. traffic signals; O. fixed lighting installations; P. pedestrian crossing design, operations, and control; and Q. roundabouts.

Recommendations by Design Element

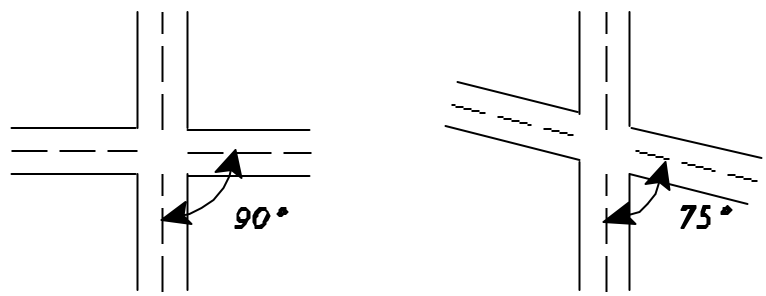
A. Design Element: Intersecting Angle (Skew)

AASHTO:1
ICG:1
ITE:1

(1) 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.

ITE:2

(2) 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.



ITE:4
MUTCD:3

(3) At skewed intersections where the approach leg to the left intersects the driver's approach leg at an angle of less than 75 degrees, the prohibition of right turn on red (RTOR) is recommended [see Recommendation I(3)].

B. Design Element: Receiving Lane (Throat) Width for Turning Operations

ICG:2
ITE:2

(1) A minimum receiving lane width of 3.6 m (12 ft) is recommended, accompanied, wherever practical, by a shoulder of 1.2 m (4 ft) minimum width.

C. Design Element: Channelization

AASHTO:4
ICG:4
ITE:4
MUTCD:4

(1) Raised channelization with sloping curbed medians is recommended over channelization accomplished through the use of pavement markings (flush), for the following operating conditions:

(1a) Left- and right-turn lane treatments at intersections on all roadways with operating speeds of less than 65 km/h (40 mi/h).

(1b) Right-turn treatments on roadways with operating speeds equal to or greater than 65 km/h (40 mi/h).

MUTCD:4

(2) Where raised channelization is implemented at intersections, it is recommended that median and island curb sides and curb horizontal surfaces be treated with retroreflectorized markings and be maintained at a minimum luminance contrast level* as follows:

(2a) *With* overhead lighting, a contrast of at least 2.0 is recommended.

(2b) W*ithout* overhead lighting, a contrast of at least 3.0 is recommended.

Contrast should be calculated according to this formula:

$$luminance\ (L)\ contrast = \frac{L_{treatment} - L_{pavement}}{L_{pavement}}$$

* Luminance is the amount of light reflected from a surface to the eye of a driver. This is different from retroreflectivity, which is a property of a material. While increasing retroreflectivity generally results in higher luminance, brightness—especially at night—may vary greatly for the same target depending upon such factors as the location and intensity of its source of illumination, and the angle at which a driver views it. It is the apparent brightness (more accurately,“luminance contrast”) of a target in its surroundings, under representative viewing conditions, that determines its visibility (detectability) and is the critical predictor of a safe driver response. Since nighttime visibility of roadway features is most problematic for older drivers, the contrast calculation for this design element should be based on nighttime luminance measures; these should be obtained under low-beam headlight illumination from a passenger vehicle at a 5-s preview distance upstream of the intersection. Direct readings of the luminance of a surface can be obtained with a hand-held light meter that has a through-the-lens viewing system to enable accurate targeting of the design element. The luminance measurements of the target and surrounding area may be obtained from any location judged to be in the line of sight of the driver at the 5-s preview distance.

C. Design Element: Channelization (Continued)

AASHTO:4

(3) If right-turn channelization is present at an intersection, an acceleration lane providing for the acceleration characteristics of passenger cars as delineated in AASHTO specifications (1994) is recommended.

ICG:4

(4) The use of sloping curbs rather than barrier curbs for channelization is recommended, except where the curbs surround a pedestrian refuge area or are being used for access control.

AASHTO:1
ICG:3
MUTCD:1

(5) 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* (FHWA, 2000) and AASHTO (1994) specifications be provided.

AASHTO:4
ICG:4

(6) 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.

D. Design Element: Intersection Sight-Distance Requirements

AASHTO:4

(1) Where determinations of intersection sight-distance requirements for any intersection maneuver (turn left, turn right, crossing) that is performed by a driver on either a major *or* a minor road incorporate a perception-reaction time (PRT) component, it is recommended that a PRT value of no less than 2.5 s be used to accommodate the slower decision times of older drivers.

AASHTO:4

(2) Where determinations of intersection sight-distance requirements for a left-turn maneuver from a major roadway by a stopped passenger car are based on a gap model (see NCHRP Report 383), it is recommended that a gap of no less than 8.0 s, plus 0.5 s for each additional lane crossed by the turning driver, be used to accommodate the slower decision times of older drivers.

E. Design Element: Offset (Single) Left-Turn Lane Geometry, Signing, and Delineation

AASHTO:4
ICG:4
ITE:4

(1) Unrestricted sight distance (achieved through positive offset of opposing left-turn lanes) is recommended whenever possible, for new or reconstructed facilities. [See figure under Recommendation (3).] This will provide a margin of safety for older drivers who, as a group, do not position themselves within the intersection before initiating a left turn.

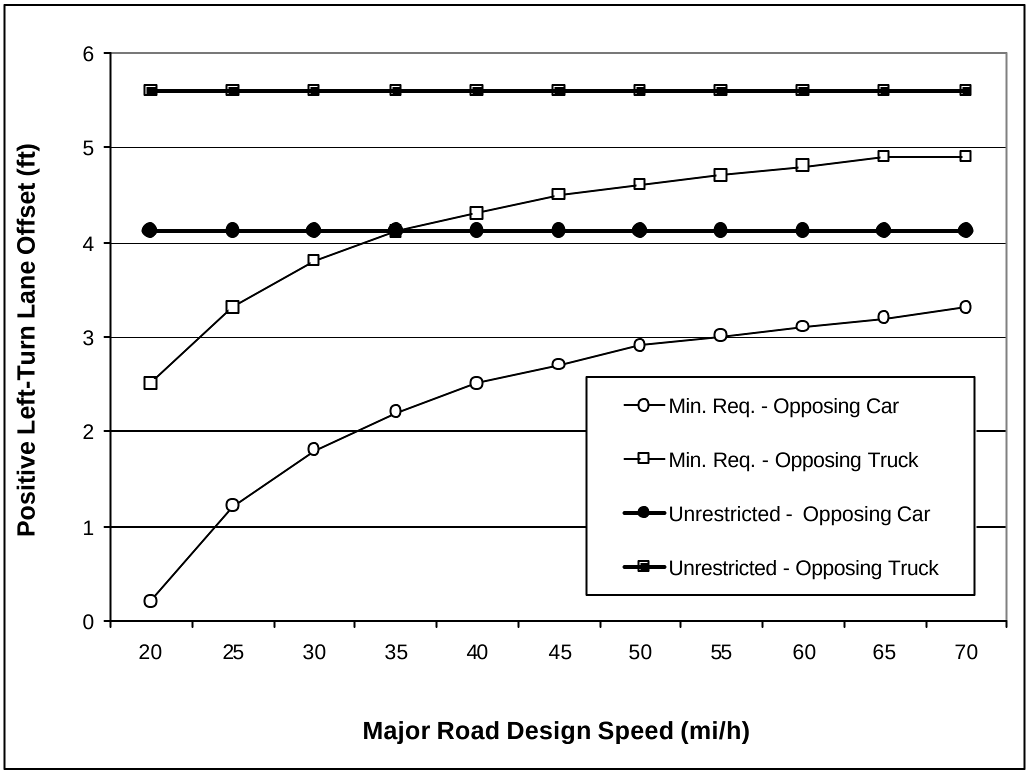
AASHTO:4
ICG:4
ITE:4

(2) At intersections where engineering judgment indicates a high probability of heavy trucks as the opposing turn vehicles during normal operations, the offsets required to provide unrestricted sight distance for opposing left-turn trucks should be used for new or reconstructed facilities. [See figure under Recommendation (3).]

E. Design Element: Offset (Single) Left-Turn Lane Geometry, Signing, and Delineation (Continued)

AASHTO:4
ICG:4
ITE:4

(3) Where the provision of unrestricted sight distance is not feasible, positive left-turn lane offsets are recommended to achieve minimum required sight distances, which vary according to (major) roadway design speed and type of opposing vehicle (passenger car or heavy truck). For left-turning traffic that must yield to opposing traffic on a major roadway, the recommended offset values to achieve minimum required sight distances* are as indicated in the figure below:



1 ft=0.305 m
1 mi/h=1.61 km/h

* The functions graphed above are yielded by computations using *either* a modified AASHTO Intersection Sight Distance (ISD) formula with PRT equal to 2.5 s *or* by gap model calculations with G equal to 8.0 s plus 0.5 s for each additional lane crossed by a turning (passenger car) driver.

E. Design Element: Offset (Single) Left-Turn Lane Geometry, Signing, and Delineation (Continued)

(4) At intersections where the left-turn lane treatment results in channelized offset left-turn lanes (e.g., a parallel or tapered left-turn lane between two medians), the following countermeasures are recommended to reduce the potential for wrong-way maneuvers by drivers turning left from a stop-controlled, intersecting minor roadway:

ITE:4
MUTCD:4

(4a) In the implementation of DIVIDED HIGHWAY CROSSING signs, and WRONG WAY, DO NOT ENTER, KEEP RIGHT, and ONE WAY signs at the intersection, as per *MUTCD* (FHWA, 2000) specifications, oversized signs (sizes larger than *MUTCD*-specified standard sizes for conventional roadways) are recommended.

MUTCD:1

(4b) It is recommended that the signs listed in Recommendation (4a) above be fabricated using retroreflective sheeting that provides for high retroreflectance overall, particularly at the widest available observation angles, to provide increased sign conspicuity and legibility for older drivers.

MUTCD:1

(4c) Retroreflective lane-use arrows for channelized left-turn lanes are recommended.

MUTCD:3

(4d) Retroreflective pavement marking extensions of the center line that scribe a path through the turn are recommended, except where extensions for opposing movements cross, to reduce the likelihood of wrong-way movements.

MUTCD:3

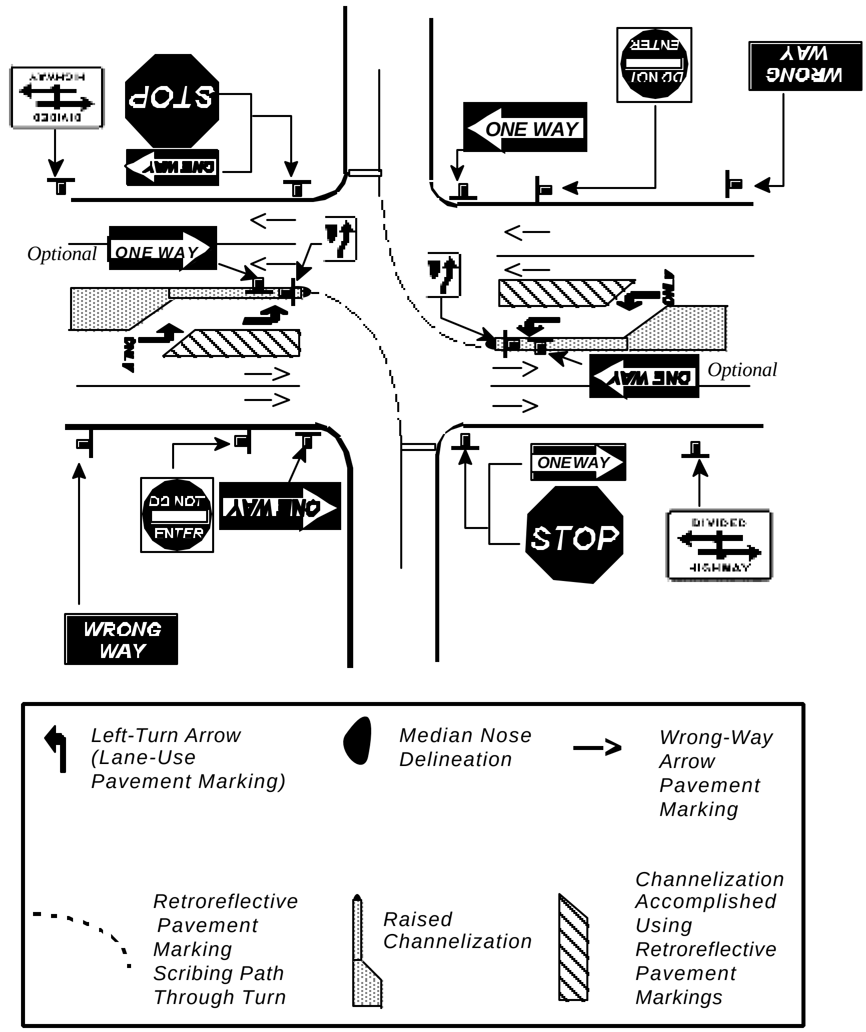
(4e) Placement of 7.1-m- (23.5-ft-) long retroreflective wrong-way arrows in the through lanes is recommended for wrong-way traffic control at locations determined to have a special need, as specified in the *MUTCD* (FHWA, 2000), sections 2A.24, 3B.19, and 2E-50.

AASHTO:1
MUTCD:2

(4f) Delineation of median noses using retroreflective treatments to increase their visibility and improve driver understanding of the intersection design and function is recommended.

E. Design Element: Offset (Single) Left-Turn Lane Geometry, Signing, and Delineation (Continued)

The diagram presented below illustrates the countermeasures as described above in Handbook Recommendations E(4a)–(4f).



Recommended signing and delineation treatments for intersections with medians 9 m (30 ft) wide or wider.

[Note: Median ONE WAY signs are optional where left-turn lanes result in narrowing of the median, and engineering judgment indicates a potential for motorist confusion.]

F. Design Element: Treatments/Delineation of Edgelines, Curbs, Medians, and Obstacles

MUTCD:4
RLH:4

(1) It is recommended that a minimum in-service luminance contrast* level between the marked edge of the roadway and the road surface be maintained as follows:

(1a) At intersections *with* overhead lighting, a contrast of 2.0 or higher is recommended.

(1b) At intersections *without* overhead lighting, a contrast of 3.0 or higher is recommended.

Contrast should be calculated according to this formula:

$$luminance\ (L)\ contrast = \frac{L_{stripe} - L_{pavement}}{L_{pavement}}$$

* See advisory comments pertaining to luminance measurement in Recommendation IC (2).

AASHTO:1
MUTCD:2

(2) It is recommended that all curbs at intersections (including median islands and other raised channelization) be delineated on their vertical face and at least a portion of the top surface, in addition to the provision of a marked edgeline on the road surface.

G. Design Element: Curb Radius

AASHTO:1
ICG:1

(1) Where roadways intersect at 90 degrees and are joined with a simple radius curve, a corner curb radius in the range of 7.5 m to 9 m (25 ft to 30 ft) is recommended as a tradeoff to: (a) facilitate vehicle turning movements, (b) moderate the speed of turning vehicles, and (c) avoid unnecessary lengthening of pedestrian crossing distances, except where precluded by high volumes of heavy vehicles.

AASHTO:4
ICG:4
ITE:4

(2) When it is necessary to accommodate turning movements by heavy vehicles, the use of offsets, tapers, and compound curves is recommended to minimize pedestrian crossing distances.

H. Design Element: Traffic Control for Left-Turn Movements at Signalized Intersections

ICG:4
ITE:4
MUTCD:4

(1) The use of protected-only operations is recommended, except when, based on engineering judgment, an unacceptable reduction in capacity will result.

ITE:4
MUTCD:4

(2) To reduce confusion during an intersection approach, the use of a separate signal face to control turning phase (versus through) movements is recommended for all operating modes.

ITE:4
MUTCD:4

(3) Consistent use of the R10-12 sign, LEFT TURN YIELD ON GREEN ●, during protected-permitted operations is recommended, with overhead placement preferred at the intersection.

*H. Design Element: Traffic Control for Left-Turn Movements at Signalized Intersections (*Continued)

AASHTO:3
MUTCD:4

(4) Where practical, the use of a redundant upstream R10-12 sign (i.e., in addition to the R10-12 sign adjacent to the signal face) is recommended to advise left-turning drivers of permitted signal operation. It is also recommended that the sign be displayed at a 3-s preview distance before the intersection, or at the beginning of the left-turn lane, as per engineering judgment, accompanied by a supplemental plaque bearing the message, AT SIGNAL. [See time-speed-distance table on page 5.]

ITE:2
MUTCD:2

(5) A leading protected left-turn phase is recommended wherever protected left-turn signal operation is implemented (as opposed to a lagging protected left-turn phase).

MUTCD:4

(6) To eliminate confusion about the meaning of the red arrow indication, it is recommended that the steady green arrow for protected-only left-turn operations terminate to a yellow arrow, then a steady circular red indication (instead of a red arrow).

AASHTO:4
ITE:1
MUTCD:1

(7) Where minimum sight-distance requirements as per recommendations for Design Element D are not practical to achieve through geometric redesign/reconstruction, or where a pattern of permitted left-turn crashes occurs, it is recommended that permitted left turns be eliminated and protected-only left-turn operations be implemented.

I. Design Element: Traffic Control for Right-Turn/RTOR Movements at Signalized Intersections

ITE:4
MUTCD:4

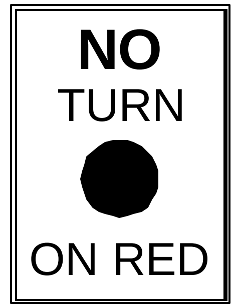
(1) It is recommended that a steady circular red indication be used at signalized intersections where a right turn on red is prohibited, instead of a red arrow indication.

ITE:4
IEC: requires

FHWA

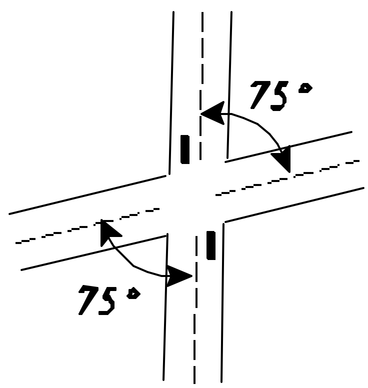
permission

(2) It is recommended that at signalized intersections where a right turn on red is prohibited, a supplemental NO TURN ON RED sign, using the design shown at right, be placed on the overhead mast arm and at a location on either the near or opposite side of the intersection where, per engineering judgment, it will be most conspicuous.



ITE:4
MUTCD:3

(3) At skewed intersections where the approach leg to the left intersects the driver's approach leg at an angle of less than 75 degrees (as indicated below), the prohibition of right turn on red (RTOR) is recommended.



MUTCD:4

(4) The posting of (black on white) signs with the legend TURNING TRAFFIC MUST YIELD TO PEDESTRIANS is recommended wherever engineering judgment indicates a clear potential for right-turning vehicles to come into conflict with pedestrians who are using the crosswalk for permitted crossing movements [shown in IP (5)].

J. Design Element: Street-Name Signing

MUTCD:4

(1) To accommodate the reduction in visual acuity associated with increasing age, a minimum letter height of 150 mm (6 in) is recommended for use on post-mounted street-name signs (*MUTCD* sign number D3) on all roads where the posted speed limit exceeds 40 km/h (25 mi/h).

MUTCD:4

(2) The use of overhead-mounted street-name signs with mixed-case letters is recommended at major intersections as a supplement to post-mounted street-name signs. Minimum letter heights of 200-mm (8-in) uppercase letters and 150-mm (6-in) lowercase letters are recommended at major intersections with approach speeds of 56 km/h (35 mi/h) or less. At major intersections with approach speeds greater than 56 km/h (35 mi/h), the minimum letter height on street-name signs should be 250-mm (10-in) uppercase and 200-mm (8-in) lowercase letters.

MUTCD:2

(3) In the design of overhead-mounted street-name signs, the use of larger letter heights will require a larger sign panel if the Standard Alphabets for Highway Signs are used. To minimize sign panel size, while accommodating the larger letter size, it is recommended that the border be eliminated on street-name signs when using Standard Alphabets.

MUTCD:4

(4) Wherever an advance intersection warning sign is erected (e.g., W2-1, W2-2, W2-3, W2-4), it is recommended that it be accompanied by an advance street-name plaque (W16-8), as shown, using 200-mm (8-in) black letters on a yellow sign panel.

J. Design Element: Street-Name Signing (Continued)

MUTCD:1

(5) The use of redundant street-name signing for major intersections is recommended, with an advance street-name sign placed upstream of the intersection at a midblock location.

MUTCD:4

(6) When different street names are used for different directions of travel on a crossroad, the names should be separated and accompanied by directional arrows on both midblock and intersection street-name signs, as shown below:

Or, a two-line sign format may be used to address support and wind load issues:

MUTCD:1

(7) For post-mounted street-name signs installed at intersections in areas of intensive land use, complex design features, and heavy traffic, it is recommended that retroreflective sheeting that provides for high retroreflectance overall, and particularly at the widest available observation angles, be used to provide increased sign conspicuity and legibility for older drivers.

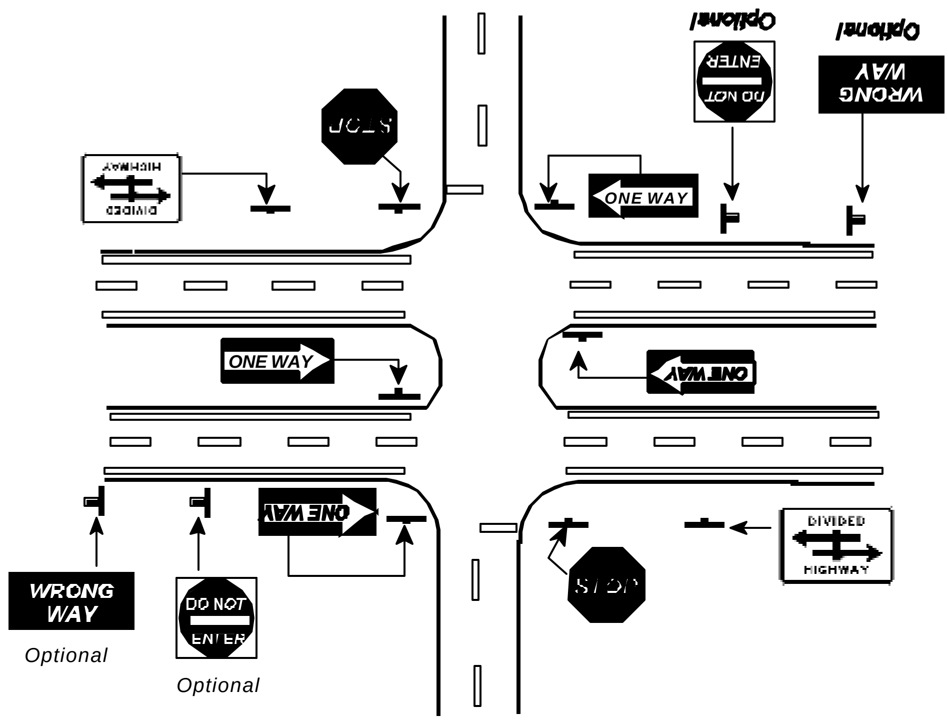
K. Design Element: One-Way/Wrong-Way Signing

MUTCD:1

(1) It is recommended that divided highways be consistently signed as shown in the configuration diagrammed below. Use of the DIVIDED HIGHWAY CROSSING sign (R6-3) is the recommended practice, pending new treatments that are demonstrated through research to provide improved comprehensibility to motorists.

MUTCD:1

(2) For divided highways with median widths less than 9 m (30 ft), the use of four ONE WAY signs is recommended, located in the left median and far-right corner of the intersection, as shown in the configuration diagrammed below.



Recommended signing configuration for medians less than 9 m (30 ft).

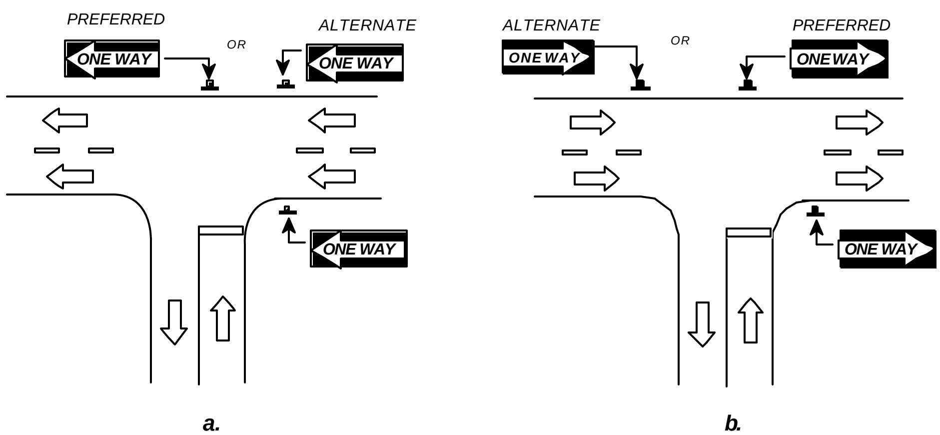
K. Design Element: One-Way/Wrong-Way Signing (Continued)

MUTCD:3

(3) For medians ranging from 9- to 13-m (30- to 42-ft) wide, or where offset left-turn lanes are used with any median width, the use of six ONE WAY signs is recommended, as diagrammed in Recommendation (4) of Design Element E (see page 20).

MUTCD:4

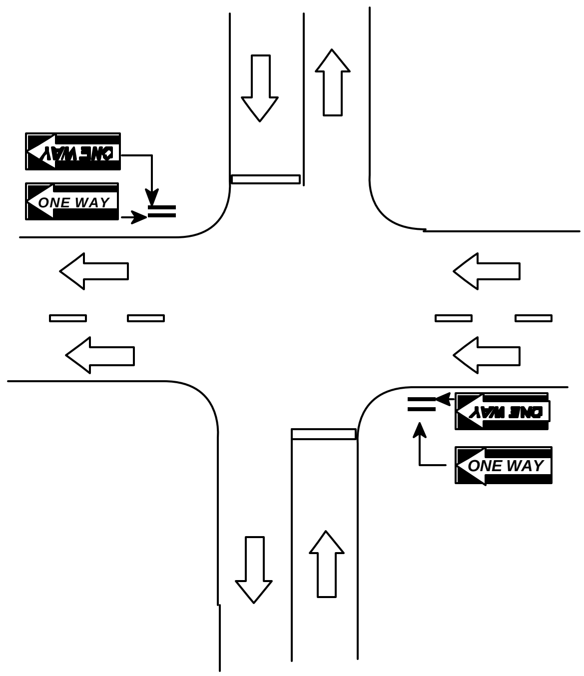
(4) For T-intersections, the use of a near-right-side ONE WAY sign and a far-side ONE WAY sign is recommended; the preferred placement for the far-side sign is opposite the extended centerline of the approach leg as shown in *MUTCD* figure 2A-6 (FHWA, 2000). Where the preferred far-side location is not feasible (e.g., because of blockage, distracting far-side land use, or an excessively wide approach leg), engineering judgment should be applied to select the most conspicuous alternate location for a driver who has not yet initiated the wrong-way turning maneuver (see diagram below).



K. Design Element: One-Way/Wrong-Way Signing (Continued)

MUTCD:4

(5) For the intersection of a one-way street with a two-way street, ONE WAY signs placed at the near-right/far-left locations are recommended, regardless of whether there is left-to-right or right-to-left traffic (see diagram below).



AASHTO:4
MUTCD:4

(6) As a general practice, the use of DO NOT ENTER and WRONG WAY signs is recommended at locations where the median width is 9 m (30 ft) and greater. Consideration should also be given to the use of these signs for median widths narrower than 9 m (30 ft), where engineering judgment indicates a special need.

L. Design Element: Stop- and Yield-Controlled Intersection Signing

Recommendations to improve the safe use of intersections by older drivers, where the need for stop control or yield control has already been determined, include the following:

MUTCD:1

(1) The use of standard size (750-mm [30-in]) STOP (R1-1) and standard size (900-mm [36-in]) YIELD (R1-2) signs, *as a minimum*, is recommended wherever these devices are implemented, with the option of using larger R1-1 (900-mm [36-in] or 1200-mm [48-in]) signs where engineering judgment indicates that greater emphasis or visibility is required.

ITE:4
MUTCD:4

(2) A *minimum* sign background (red area) retroreflectivity level (i.e., coefficient of retroreflection [R_A]) below which a need for sign replacement is indicated, is recommended for STOP (R1-1) and YIELD (R1-2) signs as follows:

(2a) 12 cd/lux/m² for roads with operating speeds lower than 65 km/h (40 mi/h).

(2b) 24 cd/lux/m² for roads with operating speeds of 65 km/h (40 mi/h) or higher.

MUTCD:4

(3) The use of a 750-mm x 450-mm (30-in x 18-in) supplemental warning sign panel (W4-4p), as illustrated, mounted below the STOP (R1-1) sign, is recommended for two-way stop-controlled intersection sites selected on the basis of crash experience; where the sight triangle is restricted; and wherever a conversion from four-way stop to two-way stop operations is implemented.

AASHTO:4
ITE:4
MUTCD:4

(4) It is recommended that a STOP AHEAD sign (W3-1a) be used where the distance at which the STOP sign is visible is less than the AASHTO stopping sight distance (SSD) at the operating speed, plus an added preview distance of at least 2.5 s. [See time-speed-distance table on page 5.]

L. Design Element: Stop- and Yield-Controlled Intersection Signing (Continued)

ITE:4

(5) The use of transverse pavement striping or rumble strips upstream of stop-controlled intersections where engineering judgment indicates a special need due to sight restrictions, high approach speeds, or a history of ran-stop-sign crashes is recommended.

M. Design Element: Devices for Lane Assignment on Intersection Approach

MUTCD:1

(1) The consistent overhead placement of lane-use control signs (e.g., R3-5, R3-6, R3-8) at intersections on a signal mast arm or span wire is recommended.

MUTCD:4

(2) 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. [See time-speed-distance table on page 5.] Signs should be mounted overhead wherever practical.

N. Design Element: Traffic Signals

MUTCD:4

(1) A *maintained* performance level of 200 cd for peak intensity of a 200-mm (8-in) red signal is recommended to ensure detectability and improve conspicuity of this critical control element.

MUTCD:2

(2) To accommodate age differences in perception-reaction time, it is recommended that an all-red clearance interval be consistently implemented, with length determined according to the Institute of Transportation Engineers (1992) expressions given below:

(2a) Where pedestrian traffic is prohibited, or no pedestrian crossing facilities are provided, use:

$$r = \frac{W + L}{V}$$

(2b) Where pedestrian crossing facilities are provided, use:

$$r = \frac{P + L}{V}$$

where:
- r = length of red clearance interval, to the nearest 0.1 s.
- W= width of intersection (m [ft]), measured from the near-side stop line to the far edge of the conflicting traffic lane along the actual vehicle path.
- P= width of intersection (m [ft]), measured from the near-side stop line to the far side of the farthest conflicting pedestrian crosswalk along the actual vehicle path.
- L= length of vehicle (recommended as 6 m [20 ft]).
- V= speed of the vehicle through the intersection (m/s [ft/s]).

MUTCD:4

(3) The consistent use of a backplate with traffic signals on all roads with operating speeds of 65 km/h (40 mi/h) or higher is recommended. The use of a backplate with signals on roads with operating speeds lower than 65 km/h (40 mi/h) is also recommended where engineering judgment indicates a need due to the potential for sun glare problems, site history, or other variables.

O. Design Element: Fixed Lighting Installations

AASHTO:4
MUTCD:4
RLH:4

(1) Wherever feasible, fixed lighting installations are recommended as follows:

- (1a) Where the potential for wrong-way movements is indicated through crash experience or engineering judgment.
- (1b) Where twilight or nighttime pedestrian volumes are high.
- (1c) Where shifting lane alignment, turn-only lane assignment, or a pavement-width transition forces a path-following adjustment at or near the intersection.

RLH:4

(2) Regular cleaning of lamp lenses, and lamp replacement when output has degraded by 20 percent or more of peak performance (based on hours of service and manufacturer's specifications), are recommended for all fixed lighting installations at intersections.

P. Design Element: Pedestrian Crossing Design, Operations, and Control

AASHTO:2
ICG:2
MUTCD:2

(1) To accommodate the shorter stride and slower gait of less capable (15th percentile) older pedestrians, and their exaggerated “start-up” time before leaving the curb, pedestrian control-signal timing based on an assumed walking speed of 0.85 m/s (2.8 ft/s) is recommended.

P. Design Element: *Pedestrian Crossing Design, Operations, and Control* (Continued)

AASHTO:4
ICG:4
ITE:4
MUTCD:4

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

(2a) An adjacent pedestrian refuge island conforming to *MUTCD* (FHWA, 2000) and AASHTO (1994) specifications be provided.

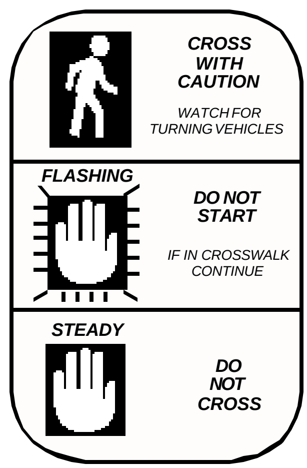
(2b) If a crosswalk is within the channelized area, it should be located as close as possible to the approach leg to maximize the visibility of pedestrians before drivers are focused on scanning for gaps in traffic on the intersecting roadway.

IEC: requires

FHWA

permission

(3) It is recommended that a placard explaining pedestrian control signal operations and presenting a warning to watch for turning vehicles be posted at the near corner of all intersections with a pedestrian crosswalk, using the design shown.

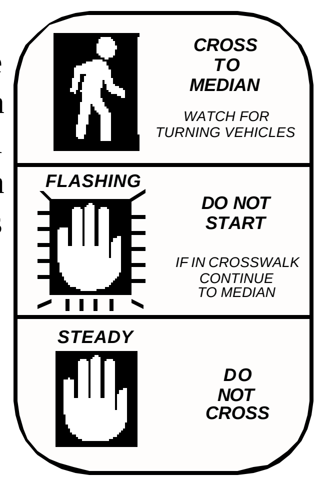


IEC: requires

FHWA

permission

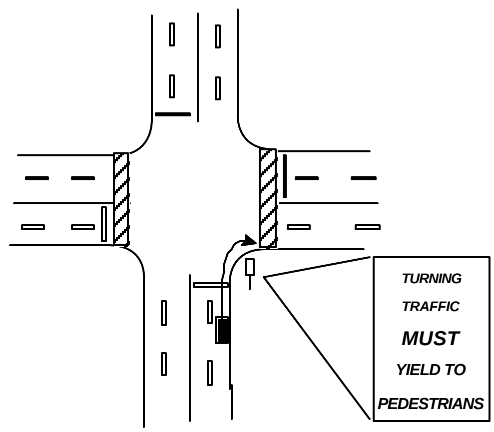
(4) It is recommended that at intersections where pedestrians cross in two stages using a median refuge island, the placard depicted in Recommendation P(3) be placed on the median refuge island, and that a placard modified as shown be placed on the near corner of the crosswalk.



P. Design Element: Pedestrian Crossing Design, Operations, and Control
(Continued)

MUTCD:4

(5) The posting of (black on white) signs with the legend TURNING TRAFFIC MUST YIELD TO PEDESTRIANS is recommended wherever engineering judgment indicates a clear potential for right-turning vehicles to come into conflict with pedestrians who are using the crosswalk for permitted crossing



movements (shown below).

MUTCD:4

(6) At intersections with high pedestrian volumes, 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:

$$LPI = (ML + PL)/2.8$$

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.

2.8* = walking speed in ft/s.

* 2.8 ft/s = 0.85 m/s

Q. Design Element: Roundabouts

Recommendations for preferred practices when a State or local highway authority has determined through engineering study to install a modern roundabout during construction or reconstruction of an intersection include the following (see the figure on the following page that depicts basic geometric elements, from *Roundabouts: An Informational Guide*):

RND:1

(1) Whenever practical, it is recommended that roundabout installations be limited to one-lane entrances and exits, and one lane of circulating traffic, with the inscribed circle diameter limited to approximately 30 m (100 ft).

RND:1

(2) It is recommended that pedestrian crossings at single-lane roundabouts be set back a minimum of 7.5 m [25 ft] behind the yield line.

RND:1

(3) To control for wrong-way movements, calm traffic, and provide a pedestrian refuge for all roundabout categories, it is recommended that raised splitter islands be used, as opposed to pavement markings, to delineate the channelization. The pedestrian crosswalk area should be designed at street level (crosswalk cut through splitter island).

Q. Design Element: Roundabouts (Continued)

RND:4

(4) To enhance the conspicuity of roundabouts in all categories, it is recommended that the sides and tops of curbs on the splitter islands and the central island be treated with retroreflective markings, and be maintained at a minimum luminance contrast level* as follows:

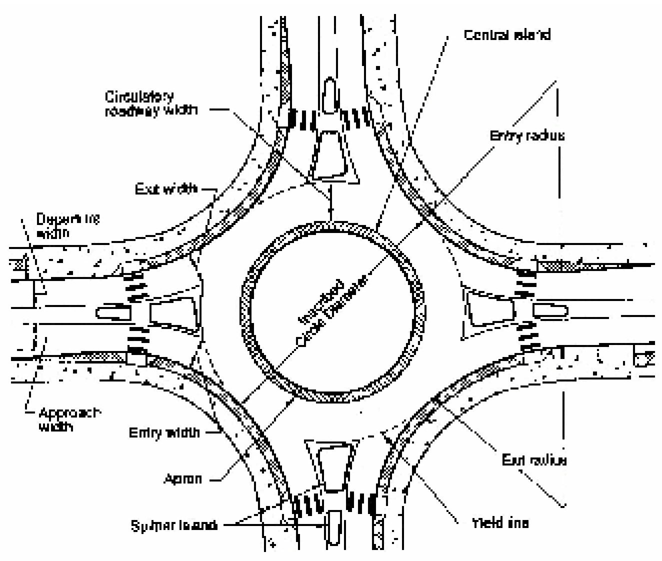
(4a) At roundabouts *with* overhead lighting, a contrast of 2.0 or higher is recommended.

(4b) At roundabouts *without* overhead lighting, a contrast of 3.0 or higher is recommended.

$$\text{luminance } (L) \text{ contrast} = \frac{L_{stripe} - L_{pavement}}{L_{pavement}}$$

Contrast should be calculated according to this formula:

* See advisory comments pertaining to luminance measurement in Recommendation IC (2).



Basic geometric elements of a roundabout.
Source: Roundabouts: An Informational Guide (FHWA, 2000)

II. INTERCHANGES (GRADE SEPARATION)

Background and Scope of Handbook Recommendations

Overall, freeways are characterized by the highest safety level (lowest fatality rates) when compared with other types of highways in rural and urban areas (American Automobile Association Foundation for Traffic Safety, 1995). At the same time, freeway interchanges have design features that have been shown to result in significant safety and operational problems. Taylor and McGee (1973) reported more than 20 years ago that erratic maneuvers are a common occurrence at freeway exit ramps, and that the number of crashes there is four times greater than at any other freeway location. Two decades later, Lunenfeld (1993) reiterated that most freeway crashes and directional uncertainty occur in the vicinity of interchanges.

Distinct patterns in the occurrence of freeway interchange crashes emerge in studies that look specifically at driver age. Staplin and Lyles (1991) conducted a statewide (Michigan) analysis of the crash involvement ratios and types of violations for drivers in four age groups: age 76 and older; ages 56 to 75; ages 27 to 55; and age 26 and younger. Using induced-exposure methods to gauge crash involvement levels, this analysis showed that drivers over age 75 were overrepresented as the driver at fault in merging and weaving crashes near interchange ramps. With respect to violation types, the older driver groups were cited most frequently for failing to yield and for improper use of lanes. Similarly, Harkey, Huang, and Zegeer's study (1996) of the precrash maneuvers and contributing factors in older driver freeway crashes indicated that older drivers were much more likely than younger drivers to be merging or changing lanes, or passing/overtaking prior to a crash, and that older drivers' failure to yield was the most common contributing factor. These data raise concerns about the use of freeway interchanges by older drivers. Broader demographic and societal changes suggest that the dramatic growth in older driver freeway travel between 1977 and 1988 reported by Lerner and Ratté (1991) will continue and even accelerate in the years ahead.

Age differences in interchange crashes and violations may be understood in terms of driving task demands and age-related diminished driver capabilities. The exit gore area is a transitional area that requires a major change in tracking. A driver (especially in an unfamiliar location) must process a large amount of directional information during a short period of time and at high speeds, while maintaining or modifying his/her position within the traffic stream. When drivers must perform guidance and navigation tasks in close proximity, the chances increase that they will become overloaded and commit errors (Lunenfeld, 1993). Erratic maneuvers resulting from driver indecisiveness in such situations include encroaching on the gore area, and even backing up on the ramp or the through lane. When weaving actions are required, the information-processing task demands for both entry and exit maneuvers are further magnified.

On a population basis, the age-related diminished capabilities that contribute most to older drivers' difficulties at freeway interchanges include losses in vision and information-processing ability, and decreased physical flexibility in the neck and upper body. Specifically, older adults show declines in static and dynamic acuity, increased sensitivity to glare, poor night vision, and reduced contrast sensitivity

(McFarland, Domey, Warren, and Ward, 1960; Weymouth, 1960; Richards, 1972; Pitts, 1982; Sekuler, Kline, and Dismukes, 1982; Owsley, Sekuler, and Siemsen, 1983). These sensory losses are compounded by the following perceptual and cognitive deficits, the first two of which are recognized as being especially critical to safety: reduction in the ability to rapidly localize the most relevant stimuli in a driving scene; reduction in the ability to efficiently switch attention between multiple targets; reduction in working memory capacity; and reduction in processing speed (Avolio, Kroeck, and Panek, 1985; Plude and Hoyer, 1985; Ponds, Brouwer, and van Wolffelaar, 1988; Brouwer, Ickenroth, Ponds, and van Wolffelaar, 1990; Brouwer, Waterink, van Wolffelaar, and Rothengatter, 1991). The most important physical losses are reduced range of motion (head and neck), which impairs visual search, and slowed response time to execute a vehicle control movement, especially when a sequence of movements—such as braking, steering, and accelerating to weave and then exit a freeway—is required (Smith and Sethi, 1975; Goggin, Stelmach, and Amrhein, 1989; Goggin and Stelmach, 1990; Hunter-Zaworski, 1990; Staplin, Lococo, and Sim, 1990; Ostrow, Shaffron, and McPherson, 1992).

One result of these age-related diminished capabilities is demonstrated by a driver who waits when merging and entering freeways at on-ramps until he/she is alongside traffic, then relies on mirror views of overtaking vehicles on the mainline to begin searching for an acceptable gap (McKnight and Stewart, 1990). Exclusive use of mirrors to check for gaps, and slowing or stopping to look for a gap, increase the likelihood of crashes and have a negative effect on traffic flow. Malfetti and Winter (1987), in a critical incident study of merging and yielding problems, reported that older drivers on freeway acceleration lanes merged so slowly that traffic was disrupted, or they stopped completely at the end of the ramp instead of attempting to approach the speed of the traffic flow before entering the mainline. In a survey of 692 older drivers, 25 percent reported that they stop on a freeway entrance ramp before merging onto the highway, and 17 percent indicated that they have trouble finding a large enough gap in which to merge onto the mainline (Knoblauch, Nitzburg, and Seifert, 1997). Thirty-four percent of the "young-old" respondents (ages 50 to 72) and 26 percent of the "old-old" respondents (ages 73 to 97) responded that they wish entrance lanes were longer. In Lerner and Ratté's research (1991), older drivers in focus group discussions commented that they experienced difficulty maintaining vehicle headway because of slower reaction times, difficulty reading signs, fatigue, mobility limitations, a tendency to panic or become disoriented, and loss of daring or confidence. Merging onto the freeway was the most difficult maneuver discussed. Needed improvements identified by these older drivers included the elimination of weaving sections and short merge areas, which would facilitate the negotiation of on-ramps at interchanges. Improvements identified to ease the exit process included better graphics, greater use of sign panels listing several upcoming exits, and other methods to improve advance signing for freeway exits.

This section will provide recommendations for highway design elements in four areas to enhance the performance of diminished-capacity drivers at interchanges: A. exit signing and exit ramp gore delineation; B. acceleration/deceleration lane design features; C. fixed lighting installations; and D. traffic control devices for restricted or prohibited movements on freeways, expressways, and ramps.

Recommendations by Design Element

A. Design Element: Exit Signing and Exit Ramp Gore Delineation

ITE:4
MUTCD:4

(1) The calculation of letter size requirements for signing at interchanges and on their approaches based on an assumption of *not more than* 10 m (33 ft) of legibility distance for each 25 mm (1 in) of letter height is recommended for new or reconstructed installations and at the time of sign replacement.

MUTCD:2

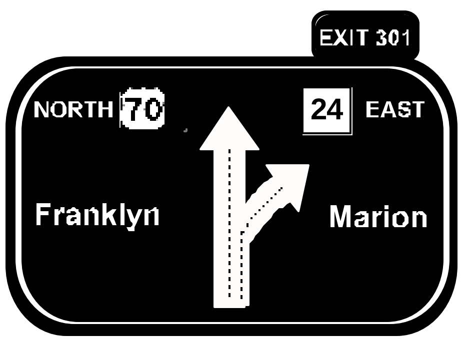
(2) To increase the reading distance of all highway destination signs, it is recommended that a mixed-case font, as presently used for overhead installations, also be used for ground-mounted signs on the side of the road (e.g., MUTCD sign numbers D1-1 to D1-3).

IEC: requires

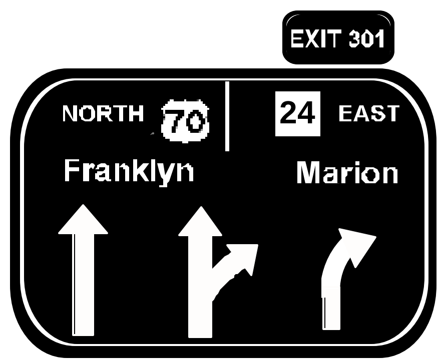
FHWA

permission

(3) A modification of upstream diagrammatic guide signing as displayed in the *MUTCD* (figure 2E-7) is recommended for new or reconstructed installations, whereby the number of arrow shafts appearing on the sign matches the number of lanes on the roadway at the sign's location (as shown below).



Existing *MUTCD* format



Recommended alternative

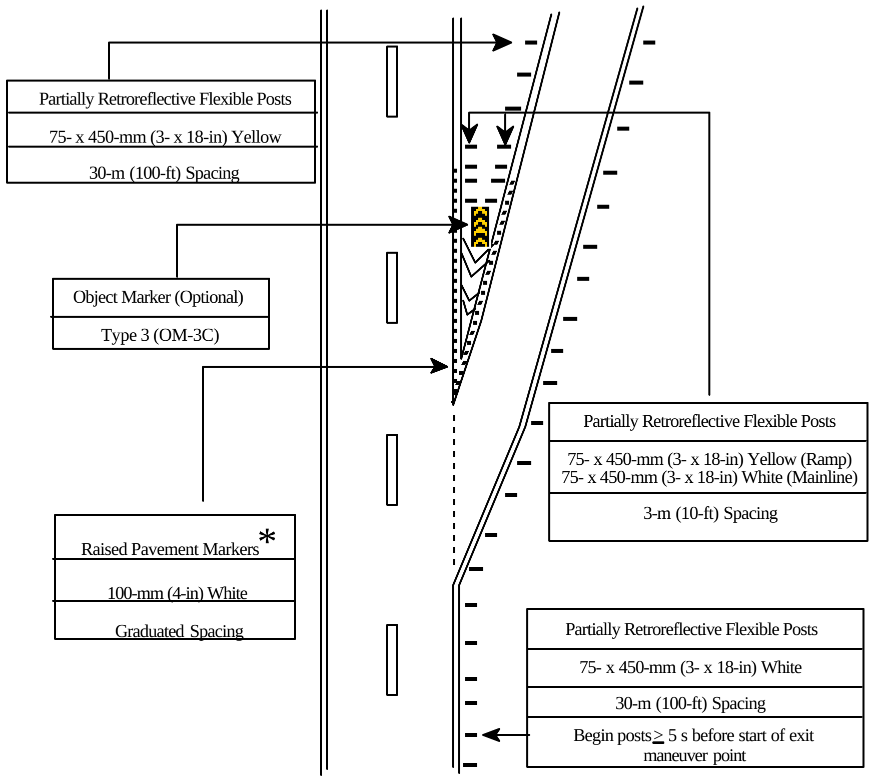
A. Design Element: Exit Signing and Exit Ramp Gore Delineation (Continued)

(4) It is recommended that:

AASHTO:4
MUTCD:4

(4a) Delineation in the vicinity of the exit gore at nonilluminated and partially illuminated interchanges include, *as a minimum*, the treatments illustrated in the figure below:

Note: Figure is not to scale.



* Snowplowable raised pavement markers may be used where appropriate for conditions.

AASHTO:4
ITE:3
MUTCD:4

(4b) Where engineering judgment has identified a hazardous gore area (e.g., containing a ditch) or other special visibility need, the minimum treatment indicated in Recommendation IIA (4a) and illustrated in the figure above should be supplemented by a Type 3 object marker (OM-3C).

B. Design Element: Acceleration/Deceleration Lane Design Features

AASHTO:4 (1) It is recommended that acceleration lane lengths be determined using the higher of AASHTO (1994) table X-4 speed change-lane criteria or NCHRP 3-35 values for a given set of operational and geometric conditions, and assuming a 65-km/h (40-mi/h) ramp speed at the beginning of the gap search and acceptance process.

AASHTO:4 (2) A parallel versus a taper design for entrance ramp geometry is recommended.

MUTCD:3 (3) It is recommended that post-mounted delineators and/or chevrons be applied to delineate the controlling curvature on exit ramp deceleration lanes.

AASHTO:2 (4) It is recommended that AASHTO (1994) decision sight-distance values be consistently applied in locating ramp exits downstream from sight-restricting vertical or horizontal curvature on the mainline (instead of locating ramps based on stopping sight-distance [SSD] or modified SSD formulas).

C. Design Element: Fixed Lighting Installations

AASHTO:4
RLH:4 (1) Complete interchange lighting (CIL) is the preferred practice, but where a CIL system is not feasible to implement, a partial interchange lighting (PIL) system comprised of two high-mast installations (e.g., 18- to 46-m- [60- to 150-ft-] high structures with 3 to 12 luminaires per structure) per ramp is recommended, with one fixture located on the inner ramp curve near the gore, and one fixture located on the outer curve of the ramp, midway through the controlling curvature.

D. Design Element: Traffic Control Devices for Restricted or Prohibited Movements on Freeways, Expressways, and Ramps

MUTCD:4 (1) To increase the legibility distance of overhead lane control signal indications for prohibited movements (red X), a double-stroke arrangement of pixels that are small (approximating a 4 mm diameter) and closely spaced (approximating 18 mm, center-to-center) is recommended.

MUTCD:4 (2) The consistent use of a 1200-mm x 750-mm (48-in x 30-in) guide sign panel with the legend FREEWAY ENTRANCE, using a minimum letter height of 200 mm (8 in) for positive guidance, as described as an option in section 2E.50 of the *MUTCD* (FHWA, 2000) and shown to the right, is recommended.

MUTCD:4 (3) Where adjacent entrance and exit ramps intersect with a crossroad, the use of a median separator 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. 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 300-mm (12-in) or wider yellow stripe bordered by yellow ceramic buttons that are touching throughout the length of the setback. In addition, it is recommended that a KEEP RIGHT (R4-7a) sign be posted on the median separator nose.

D. Design Element: Traffic Control Devices for Restricted or Prohibited Movements on Freeways, Expressways, and Ramps (Continued)

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

MUTCD:4

(4a) A minimum size for R5-1 of 900 mm x 900 mm (36 in x 36 in) and 1200 mm x 800 mm (48 in x 32 in) for R5-1a is recommended, with corresponding increases in letter size.

MUTCD:1

(4b) To provide increased sign conspicuity and legibility for older drivers, retroreflective fluorescent red sheeting materials that provide for high retroreflectance overall, and particularly at the widest available observation angles, are recommended.

MUTCD:4

(4c) Where engineering judgment indicates an exaggerated risk of wrong-way movement crashes, it is recommended that both the R5-1 and R5-1a signs be installed on both sides of the ramp, placed in accordance with the MUTCD.

IEC: requires FHWA permission

(4d) 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 900 mm (36 in) above the pavement (measured from the road surface to the bottom of the sign), or the lowest value above 900 mm that is practical when the presence of snow, vegetation, or other obstructions is taken into consideration.

* This does not meet the standards set by the by MUTCD Section 2A.18 or the Roadside Design Guide Section 4.3.3, so the reasons for choosing to implement this recommendation should be clearly documented by the authorized agency.

MUTCD:3

(5) The application of 7.1-m- (23.5-ft-) long wrong-way arrow pavement markings (see *MUTCD* section 3B.19, figure 3B-22) near the terminus on all exit ramps is recommended.

III. ROADWAY CURVATURE AND PASSING ZONES

Background and Scope of Handbook Recommendations

Crashes on horizontal curves have been recognized as a considerable safety problem for many years. Crash studies indicate that roadway curves experience a higher crash rate than tangents, with rates ranging from one-and-a-half to three to four times higher than tangents (Glennon, Neuman, and Leisch, 1985; Zegeer, Stewart, Reinfurt, Council, Neuman, Hamilton, Miller, and Hunter, 1990; Neuman, 1992). Lerner and Sedney (1988) reported anecdotal evidence that horizontal curves present problems for older drivers. Also, analyses of crash data in Michigan found that older drivers were involved in crash situations on horizontal curves as a result of driving too fast for the curve or, more significantly, because they were surprised by the curve alignment (Lyles, Kane, Vanosdall, and McKelvey, 1997). In reviewing literature on driver behavior on rural road curves, Johnston (1982) reported that horizontal curves that are less than 600 m (1968 ft) in radius on two-lane rural roads, and those requiring a substantial reduction in speed from that prevailing on the preceding tangent section, were disproportionately represented among crash sites.

Successful curve negotiation depends on the choice of appropriate approach speed and adequate lateral positioning through the curve. Many studies have shown that loss-of-control crashes result from an inability to maintain a lateral position through the curve because of excessive speed, with inadequate deceleration in the approach zone. These problems, in turn, stem from a combination of factors, including poor anticipation of vehicle control requirements, induced by the driver's prior speed, and inadequate perception of the demands of the curve.

Many studies report a relationship between horizontal curvature (and the degree of curvature) and the total percentage of crashes by geometric design feature on the highways. The reasons for these crashes are related to the following inadequate driving behaviors:

- Deficient skills in negotiating curves, especially those of more than 3 degrees (Eckhardt and Flanagan, 1956).
- Exceeding the design speed on the curve (Messer, Mounce, and Brackett, 1981).
- Exceeding the design of the vehicle path (Glennon and Weaver, 1971; Good, 1978).
- Failure to maintain appropriate lateral position in the curve (McDonald and Ellis, 1975).
- Incorrect anticipatory behavior of curve speed and alignment when approaching the curve (Messer et al., 1981; Johnston, 1982).
- Inadequate appreciation of the degree of hazard associated with a given curve (Johnston, 1982).

With respect to vertical curves, design policy is based on the need to provide drivers with adequate stopping sight distance (SSD). That is, enough sight distance must exist to permit drivers to see an obstacle soon enough to stop for it under some set of reasonable worst-case conditions. The parameters that determine sight distance on crest vertical curves include the change of grade, the length of the curve, the height above the ground of the driver's eye, and the height of the obstacle to be seen. SSD is determined by the driver's reaction time, speed of the vehicle, and tire-pavement coefficient of friction. There is some concern with the validity of the SSD model that has been in use for more than 50 years, however. Current practice assumes an obstacle height of 150 mm (6 in) and a locked-wheel, wet-pavement stop (AASHTO, 1994). Minimum lengths of crest vertical curves are based on sight distance and driver comfort. These criteria do *not* currently include adjustments for age-related effects in driving performance measures, which would suggest an even more conservative approach. At the same time, the general lack of empirical data demonstrating benefits for limited sight-distance countermeasures has led some to propose liberalization of model criteria, such as obstacle height (Neuman, 1989; Fambro, Fitzpatrick, and Koppa, 1997).

Standards and criteria for sight distance, horizontal and vertical alignment, and associated traffic control devices are based on the following driver performance characteristics: detection and recognition time, perception-reaction time, decision and response time, time to perform brake and accelerator movements, maneuver time, and (if applicable) time to shift gears. However, these values have typically been based on driving performance (or surrogate driving measures) of the entire driving population, or have been formulated from research biased toward younger (college age) as opposed to older driver groups. The models underlying these design standards and criteria therefore have not, as a rule, included variations to account for slower reaction time or other performance deficits consistently demonstrated in research on older driver response capabilities. In particular, diminished visual performance (reduced acuity and contrast sensitivity), physical capability (reduced strength to perform control movements and sensitivity to lateral force), cognitive performance (attentional deficits and declines in choice reaction time in response to unpredictable stimuli), and perceptual abilities (reduced accuracy of processing speed-distance information as required for gap judgments) combine to make the task of negotiating the highway design elements addressed in this section more difficult and less forgiving for older drivers.

This section will provide recommendations to enhance the performance of diminished-capacity drivers as they negotiate roadway curvature and passing zones, focusing on four design elements: A. pavement markings and delineation on horizontal curves; B. pavement width on horizontal curves; C. crest vertical curve length and advance signing for sight-restricted locations; and D. passing zone length, passing sight distance, and passing/overtaking lanes on two-lane highways.

Recommendations by Design Element

A. Design Element: Pavement Markings and Delineation on Horizontal Curves

MUTCD:4 (1) Recommendations for the maintained brightness of white edgelines on horizontal curves are presented in terms of measured* effective luminance contrast level (C), where:

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

* See advisory comments pertaining to luminance measurement in Recommendation IC (2).

Specifically,

(1a) On highways without median separation of opposing directions of traffic, the recommended minimum in-service contrast level for edgelines on horizontal curves is 5.0.

(1b) On highways where median barriers effectively block the drivers' view of oncoming headlights or where median width exceeds 15 m (50 ft), the recommended minimum in-service contrast level for edgelines on horizontal curves is 3.75.

MUTCD:4 (2) For horizontal curves with radii less than 1000 m (3280 ft), it is recommended that standard centerline markings be supplemented with raised pavement markers (RPM's) installed at standard spacing (i.e., 12 m [40 ft] apart), and that they be applied for a distance of 5 s of driving time (at 85th percentile speed) on the approach to the curve and continued throughout the length of the curve. [See time-speed-distance table on page 5.]

A. Design Element: Pavement Markings and Delineation on Horizontal Curves
(Continued)

MUTCD:4

(3) In addition to the installation of chevron alignment signs (W1-8) as specified in section 2C.10 of the MUTCD (FHWA, 2000), it is recommended that:

(3a) Roadside post-mounted delineation devices (PMD's) be installed at a maximum spacing (S) of 12 m (40 ft) on all horizontal curves with a radius (R) of 185 m (600 ft) or less.

(3b) The standard formula specified in MUTCD section 3D.4, Table 3D-1(FHWA, 2000) be used to define roadside delineator spacing intervals for curves of radii more than 185 m (600 ft), where:

English:

$$S = 3\sqrt{R - 50}$$

Metric:

$$S = 1.7\sqrt{R - 15}$$

Where: R=radius of curve (in feet) R=radius of curve (in meters)
S=spacing on curve (in feet) S=spacing on curve (in meters)

B. Design Element: Pavement Width on Horizontal Curves

AASHTO:4
ITE:4

(1) For horizontal curves on two-lane non-residential facilities that have $\geq$ 3 degrees of curvature, it is recommended that the width of the lane plus the paved shoulder be at least 5.5 m (18 ft) throughout the length of the curve (assuming AASHTO [1994] design values for superelevation and coefficient of side friction).

C. Design Element: Crest Vertical Curve Length and Advance Signing for Sight-Restricted Locations

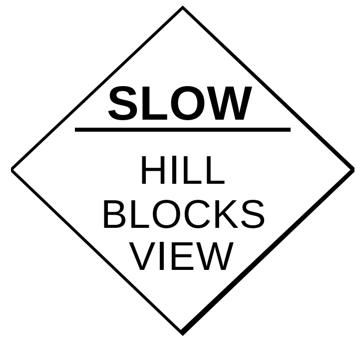
MUTCD:1

(1) To accommodate the exaggerated decline among older drivers in response to unexpected hazards, it is recommended that the present criterion of 150 mm (6 in) for obstacle height on crest vertical curves be preserved in the design of new and reconstructed facilities.

IEC: requires

FHWA

(2) Where a need has been determined for installation or replacement of a device to warn motorists that sight distance is restricted by a crest vertical curve, the message SLOW / HILL BLOCKS VIEW is recommended, using the special sign size of 900 mm x 900 mm (36 in x 36 in) as a minimum.



MUTCD:4

(3) If a signalized intersection is obscured by vertical or horizontal curvature in a manner that the signal phase becomes visible at a preview distance of 8 s or less (at operating speed), then it is recommended that the standard (W3-3) advance signal warning sign be augmented with a yellow placard bearing the black legend PREPARE TO STOP and a flashing yellow beacon interconnected with the traffic signal controller. The yellow flasher 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. [See time-speed-distance table on page 5.]

D. Design Element: Passing Zone Length, Passing Sight Distance, and Passing/Overtaking Lanes on Two-Lane Highways

AASHTO:2
ITE:2
MUTCD:2

(1) To accommodate age-related difficulties in judging gaps and longer decision-making and reaction times exhibited by older drivers, the most conservative minimum required passing sight distance (PSD) values, as determined by AASHTO (1994, table III-5), are recommended.

MUTCD:1
MUTCD:3

(2) Use of the *MUTCD* (FHWA, 2000) special-size (1200-mm x 1600-mm x 1600-mm [48-in x 64-in x 64-in]) NO PASSING ZONE pennant (W14-3), or the standard size (900 mm x 1200 mm x 1200 mm [36 in x 48 in x 48 in]) using fluorescent yellow retroreflective sheeting, as a high-conspicuity supplement to conventional centerline pavement markings at the beginning of no passing zones is recommended.

AASHTO:4
ITE:4

(3) To the extent feasible for new or reconstructed facilities, the implementation of passing/overtaking lanes (in each direction) at intervals of no more than 5 km (3.1 mi) is recommended.

IV. CONSTRUCTION/WORK ZONES

Background and Scope of Handbook Recommendations

Highway construction and maintenance zones deserve special consideration with respect to older driver needs because of their strong potential to violate driver expectancy. Alexander and Lunenfeld (1986) properly emphasized that driver expectancy is a key factor affecting the safety and efficiency of all aspects of the driving task. Consequently, it is understandable that crash analyses consistently show that more crashes occur on highway segments containing construction zones than on the same highway segments before the zones were implemented (Juergens, 1972; Graham, Paulsen, and Glennon, 1977; Lisle, 1978; Nemeth and Migletz, 1978; Paulsen, Harwood, and Glennon, 1978; Garber and Woo, 1990; Hawkins, Kacir, and Ogden, 1992).

Work-zone traffic control must provide adequate notice to motorists that describes the condition ahead, the location, and the required driver response. Once drivers reach a work zone, pavement markings, signing, and channelization must be conspicuous and unambiguous in providing guidance through the area. The National Transportation Safety Board (NTSB, 1992) stated that the *MUTCD* guidelines concerning signing and other work-zone safety features provide more than adequate warning for a *vigilant* driver, but may be inadequate for an inattentive or otherwise impaired driver. It is within this context that functional deficits associated with normal aging, as described below, may place older drivers at greater risk when negotiating work zones.

In a crash analysis at 20 case-study work-zone locations, among the most frequently listed contributing factors were driver attention errors and failure to yield the right-of-way (Pigman and Agent, 1990). Older drivers are most likely to demonstrate these deficits. Research on selective attention has documented that older adults respond much more slowly to stimuli that are unexpected (Hoyer and Familant, 1987), suggesting that older adults could be particularly disadvantaged by changes in roadway geometry and operations such as those found in construction zones. There is also research indicating that older adults are more likely to respond to new traffic patterns in an “automatized” fashion, resulting in more frequent driver error (Fisk, McGee, and Giambra, 1988). To respond in situations that require decisions among multiple and/or unfamiliar alternatives, with unexpected path-following cues, drivers’ actions are described by *complex reaction times* that are longer than reaction times in simple situations with expected cues. In Mihal and Barrett’s analysis (1976) relating simple, choice, and complex reaction time to crash involvement, only an increase in complex reaction time was associated with crashes. The relationship with driver age was most striking: the correlation between complex reaction time and crash involvement increased from r= 0.27 for the total analysis sample (all ages) to r= 0.52 when only older adults were included. Such data suggest that in situations where there is increased complexity in the information to be processed by drivers—such as in work zones—the most relevant information must be communicated in a dramatic manner to ensure that it receives a high priority by older individuals.

Compounding their exaggerated difficulties in allocating attention to the most relevant aspects of novel driving situations, diminished visual capabilities among older drivers are well documented (McFarland, Domey, Warren, and Ward, 1960; Weymouth, 1960; Richards, 1972; Pitts, 1982; Sekuler, Kline, and Dismukes, 1982; Owsley, Sekuler, and Siemsen, 1983; Wood and Troutbeck, 1994). Deficits in static and dynamic acuity and contrast sensitivity, particularly under low-luminance conditions, make it more difficult for them to detect and read traffic signs, to read variable message signs, and to detect pavement markings and downstream channelization devices. Olson (1988) determined that for a traffic sign to be noticed at night in a visually complex environment, its reflectivity must be increased by a factor of 10 to achieve the same level of conspicuity as in a low-complexity environment. Mace (1988) asserted that the minimum required visibility distance—the distance from a traffic sign required by drivers in order to detect the sign, understand the situation, make a decision, and complete a vehicle maneuver before reaching a sign—is increased significantly for older drivers due to their poorer visual acuity and contrast sensitivity, coupled with inadequate sign luminance and legend size. Other age-related deficits cited by Mace (1988) include lowered driver alertness, slower detection time in complex roadway scenes due to distraction from irrelevant stimuli, increased time to understand unclear messages such as symbols, and slower decision making.

In a mail survey of 1,329 American Association of Retired Persons (AARP) members ages 50 to 97, conducted to identify older driver freeway needs and capabilities, 21 percent of the respondents indicated that they have problems with accurately judging distances in construction zones (Knoblauch, Nitzburg, and Seifert, 1997). These drivers reported additional problems in negotiating work zones, including congestion/traffic; lack of adequate warning; narrow lanes; lane closures and lane shifts; and difficulty staying in their lane.

This section will provide recommendations to enhance the performance of diminished-capacity drivers as they approach and travel through construction/work zones, keyed to five specific design elements: A. lane closure/lane transition practices; B. portable changeable (variable) message signing practices; C. channelization practices (path guidance); D. delineation of crossovers/alternate travel paths; and E. temporary pavement markings.

Recommendations by Design Element

A. Design Element: Lane Closure/Lane Transition Practices

MUTCD:4

(1) At construction/maintenance work zones on high-speed roadways (where the posted speed limit is 72 km/h [45 mi/h] or greater) and divided highways, the consistent use of a flashing arrow panel located at the taper for each lane closure is recommended.

ITE:4
MUTCD:4

(2) In implementing advance signing for lane closures as per MUTCD Part 6, it is recommended that:

A supplemental (portable) changeable message sign (CMS) displaying the one-page (phase) message LEFT (RIGHT, CENTER) LANE CLOSED should be placed 800 to 1600 m (2625 to 5250 ft) upstream of the lane closure taper.

or

Redundant static signs should be used, with a minimum letter height of 200 mm (8 in) and fluorescent orange retroreflective sheeting that provides high retroreflectance at the widest available observation angle, where both the first upstream sign (e.g., W20-1) and the second sign (e.g., W20-5) encountered by the driver are equipped with flashing warning lights throughout the entire time period of the lane closure.

B. Design Element: Portable Changeable (Variable) Message Signing Practices

ITE:2
MUTCD:4

(1) It is recommended that no more than two phases be used on a changeable message sign (CMS); if a message cannot be conveyed in two phases, multiple CMS's and/or a supplemental highway advisory radio message should be used.

MUTCD:4

(2) It is recommended that each phase of a CMS message be displayed for a minimum of 3 s.

MUTCD:4

(3) 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?*).

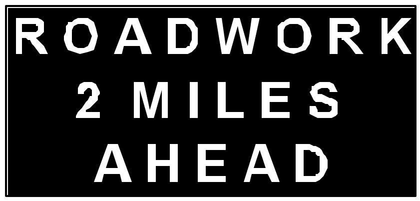
ITE:4
MUTCD:4

(4) For CMS messages split into two phases, a total of no more than four *unique* units of information should be presented.

B. Design Element: Changeable (Variable) Message Signing Practices
(Continued)

ITE:4
MUTCD:4

(5) When a portable 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. For example:



Phase 1

Phase 2

If legibility distance restrictions rule out a two-phase display, the use of abbreviations [as specified in the MUTCD (FHWA, 2000)] plus elimination of the problem statement is the recommended strategy to allow for the presentation of the entire message in one phase:

B. Design Element: Changeable (Variable) Message Signing Practices
(Continued)

(6) For superior legibility, it is recommended that:

MUTCD:4 (6a) Only single-stroke fonts should be used for displays of alphanumeric characters on portable CMS's with the conventional 5- x 7-pixel matrix; double-stroke fonts should be avoided.

MUTCD:4 (6b) As new portable CMS's 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.

C. Design Element: Channelization Practices (Path Guidance)

(1) The following minimum dimensions or properties for channelizing devices used in highway work zones are recommended to accommodate the needs of older drivers:

MUTCD:4 (1a) Traffic cones—900 mm (36 in) high, with two bands of retroreflective material totaling at least 300-mm- [12-in-] wide for nighttime operations.

MUTCD:4 (1b) Tubular markers—1050 mm (42 in) high, with a single band of retroreflective material at least 300-mm- [12-in-] wide for nighttime operations.

MUTCD:1 (1c) Vertical (striped) panels—300 mm (12 in) wide.

MUTCD:4 (1d) Chevron panels (W1-8) modified in color to be used in a work zone (white on orange)—450 mm (18 in) wide and 600 mm (24 in) high.

MUTCD:2 (1e) Barricades—300-mm x 900-mm (12-in x 36-in) minimum dimension.

MUTCD:4 (1f) Drums—450 mm x 900 mm (18 in x 36 in), with high-brightness sheeting for the orange and white retroreflective stripes (as per *MUTCD* guidelines).

MUTCD:4 (2) It is recommended that channelizing devices through work zones (in non-crossover applications) be spaced at no more than a distance in feet equal to the speed limit through the work zone <u>in miles per hour</u> (e.g., in 40-mi/h work zone, channelizing devices should be spaced at no farther apart than 40 ft). Where engineering judgment indicates a special need for speed reduction where there is horizontal curvature or through the taper for a lane closure, spacing of channelizing devices at a distance in feet equal to no more than half of the speed limit <u>in miles per hour</u> is recommended (e.g., in a 40-mi/h zone, space the devices no farther apart than 20 ft).

MUTCD:4 (3) The use of side reflectors with cube-corner lenses or reflectors (facing the driver) mounted on top of concrete safety-shaped barriers and related temporary channelizing barriers is recommended, spaced (in feet) at not more than the construction zone speed limit (<u>in miles per hour</u>) through a work zone.

D. Design Element: Delineation of Crossovers/Alternate Travel Paths

MUTCD:1

(1) The use of positive barriers in transition zones and positive separation (channelization) between opposing two-lane traffic throughout a crossover is recommended, for intermediate- and long-term-duration work zones, for all roadway classes except residential.

MUTCD:4

(2) A minimum spacing (in feet) of one-half the construction zone speed limit (in miles per hour) for channelizing devices (other than concrete barriers) is recommended in transition areas, and through the length of the crossover, and in the termination area downstream (where operations as existed prior to the crossover resume).

MUTCD:4

(3) The use of side reflectors with cube-corner lenses spaced (in feet) at not more than the construction zone speed limit (in miles per hour) on concrete channelizing barriers in crossovers (or alternately the use of retroreflective sheeting on plastic glare-control louvers [paddles] placed in crossovers) is recommended.

MUTCD:4

(4) It is recommended for construction/work zones on high-volume roadways that plastic glare-control louvers (paddles) be mounted on top of concrete channelizing barriers, when used in transition and crossover areas, at a spacing of not more than 600 mm (24 in).

E. Design Element: Temporary Pavement Markings

MUTCD:2

(1) Where temporary pavement markings shorter than the 3-m (10-ft) standard length are implemented, it is recommended that a raised pavement marker be placed at the center of the gap between successive markings.

V. HIGHWAY-RAIL GRADE CROSSINGS (PASSIVE)

Background and Scope of Handbook Recommendations

According to the Federal Railroad Administration (FRA, 1999), in 1998, there were 3,508 highway-rail grade crossing crashes, resulting in 431 fatalities and 1,303 injuries. The majority of these incidents (64 percent) occurred during the day, 31 percent occurred at night, and 5 percent occurred during dusk/dawn. Fifty-five percent of the crashes in 1998 occurred at crossings with passive controls. In a National Transportation Safety Board study (NTSB, 1998), driver error was cited as the probable cause of the crash in 49 of 60 vehicle crashes analyzed at highway grade crossings with passive controls.

Klein, Morgan, and Weiner (1994) analyzed Fatal Analysis Reporting System (FARS) data from 1975 to 1992 to determine the characteristics of drivers involved in highway-rail grade crossings, and the circumstances under which such crashes occurred. This analysis indicated that drivers ages 25 to 34 are involved in the highest percentage (almost 25 percent) of all fatal rail crossing crashes, followed by drivers ages 16 to 20 (approximately 18 percent). Drivers in these age groups also show the highest involvement in all fatal crashes and all fatal intersection crashes, based on crash frequency data uncorrected for exposure. By contrast, drivers ages 65 to 74 were involved in 6.5 percent of fatal railroad crossing crashes and drivers ages 74 and older account for almost 5 percent of the railroad crossing fatalities. Again, these data do not reflect level of exposure. However, the data show that the percentage of drivers ages 65 to 74 who are involved in fatal rail crossing crashes is slightly more than the percentage of drivers in this age group who are involved in all fatal crashes (4.6 percent) and about the same as those involved in fatal intersection crashes (6.2 percent), which is the maneuver category for which seniors are most at risk. Notably, the proportion of older drivers involved in highway-rail grade crossing crashes at night is higher than the proportion of older drivers in vehicle-involved crashes at night, suggesting special problems associated with the use of these facilities under reduced visibility conditions.

There are several age-related diminished capabilities that may make the task of safely negotiating highway-rail grade crossings more difficult for older drivers. Well-documented losses in visual acuity and contrast sensitivity with advancing age (Burg, 1967; Ball and Owsley, 1991; Ball, Owsley, Sloane, Roenker, and Bruni, 1993; Decina and Staplin, 1993) may delay substantially the detection of critical elements such as the standard crossbuck or warning symbol during a motorist's approach to a crossing, and may preclude detection of a train actually present at the crossing until impact is imminent, especially at night. While the analyses of Klein et al. (1994) paint a compelling picture of young males engaging in intentionally risky behavior as a significant component of the crash problem at rail crossings, the technical literature suggests that willful noncompliance with traffic control devices by seniors at these sites will not be a major problem—*if* they (visually) detect and comprehend the advisory, warning, and regulatory information conveyed by these devices in time to respond safely.

Expectancy also plays a role in where and when drivers look for trains and, consequently, train detection (Raslear, 1995). A driver who is familiar with a crossing and rarely or never encounters a train during the time period he or she uses the crossing is more likely to miss seeing a train than either the driver who is unfamiliar with the crossing and therefore has no expectations about train frequency, or the driver who is familiar with the crossing and frequently encounters trains during the time period that he or she crosses the tracks. Drivers who don't expect trains do not look for them. As a consequence, per train, crash rates are higher for crossings with the lowest frequency of trains (Raslear, 1995). Enhancing the conspicuity and comprehension of design elements at passive crossings, plus the use of signing that orients drivers' attention toward trains and advises drivers on the appropriate action to be taken, are thus top priorities.

Comprehension of highway-rail crossing traffic control devices and performance of related information-processing tasks may be expected to pose disproportionate difficulty for older drivers. Although the crossbuck sign is a regulatory sign that serves as an implied YIELD sign, researchers consistently report that drivers do not understand the message it is intended to convey (Bridwell, Alicandri, Fischer, and Kloeppel, 1993; Fambro, Shull, Noyce, and Rahman, 1997).

Furthermore, assuming that a driver has been properly alerted to the need to search for an approaching train by design elements upstream and at the crossing, has slowed, and has begun to actively scan the tracks in each direction, the perception-reaction time (PRT) for a decision either to stop or to proceed, plus the subsequent execution of a brake or accelerator response, draw upon abilities found to slow significantly among the elderly (Staplin and Fisk, 1991; Goggin, Stelmach, and Amrhein, 1989; Stelmach, Goggin, and Amrhein, 1988). Whereas AASHTO (1994) uses a PRT of 2.5 s for calculating the sight triangle at passive grade crossings, over a decade ago, Gordon, McGee, and Hooper (1984) recommended that a full second be added to this design value to accommodate the 85th percentile driver. With the ever-increasing number and percentage of senior drivers, the need to refocus attention on this issue is urgent.

Additional insight is provided by Leibowitz (1985), who showed that inaccurate judgments of train speed and distance may make drivers' decisions to cross hazardous, due to perceptual illusions. Most drivers are not aware of the effects of the illusions of perspective, train size, and velocity (e.g., the bigger the object, the slower it appears to be moving), and this results in unsafe crossing decisions. Kinnan (1993) states that, in most cases, the driver believes the decision to cross is a rational one; most motorists seriously underestimate the risk because they can't properly gauge the speed of the train or its distance from the crossing. This problem will only be exacerbated by the age-related decline in the ability to integrate speed and distance information, as reported by Staplin, Lococo, and Sim (1993) for the judgment of gaps at intersections.

Finally, age-related hearing loss may contribute to a failure to detect a train approaching a crossing. According to government statistics (DHHS, 1994), approximately 30 to 35 percent of people ages 65 to 75 have a hearing loss, increasing to 40 percent for persons over the age of 75. Janke (1994) reported that totally deaf males have more crashes than their non-deaf counterparts, and drivers who wear hearing aids have an increased risk of crashing compared to drivers who do not wear them (excluding individuals who formerly wore hearing aids then discarded them, who had an even worse driving record). Thus, auditory train signals may not be completely effective as a secondary warning system for visually impaired drivers or drivers who neglect to properly scan at rail crossings if they are also hearing impaired. At the same time, data show that audible warnings can help reduce nighttime crashes, as evidenced by the 195 percent increase in collisions in Florida as a result of a nighttime whistle ban between 10:00 p.m. and 6:00 a.m. (Kinnan, 1993). Raslear's (1995) crash prediction model indicates that the use of the train whistle reduces the field of visual search from 180° to 10°, which, in turn, reduces the visual search time by a factor of 18. By decreasing visual search time, the train whistle decreases the probability of a crash.

Though few studies have directly measured the effectiveness of countermeasures for older drivers in this arena, sufficient data exist to explain performance errors among the population at large to support highway-rail grade crossing design element recommendations for passive crossing control devices that offer the greatest promise to improve safety for older road users.

Recommendations by Design Element

A. Design Element: Passive Crossing Control Devices

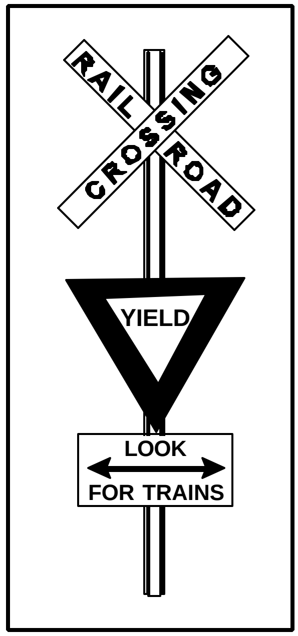
(1) To increase the conspicuity and comprehensibility of elements marking the location of the grade crossing under all operating conditions, it is recommended that:

MUTCD:4

(1a) The front and back of the crossbuck post be delineated (full length) with white high-brightness retroreflective sheeting with a minimum width of 50 mm (2 in).

MUTCD:4

(1b) A sign assembly, including a YIELD (R1-2) sign plus a supplemental panel below containing the legend LOOK FOR TRAINS and a bi-directional arrow, be added to the crossbuck post (as shown at right), in such a manner that the R1-2 sign is retroreflectorized with durable fluorescent sheeting, is no smaller than the *MUTCD* standard size (900 mm [36 in]), is mounted as close to 1200 mm (48 in) above the ground as is practical in a given location, and the supplemental panel consists of 100-mm (4-in) black letters on a white background.



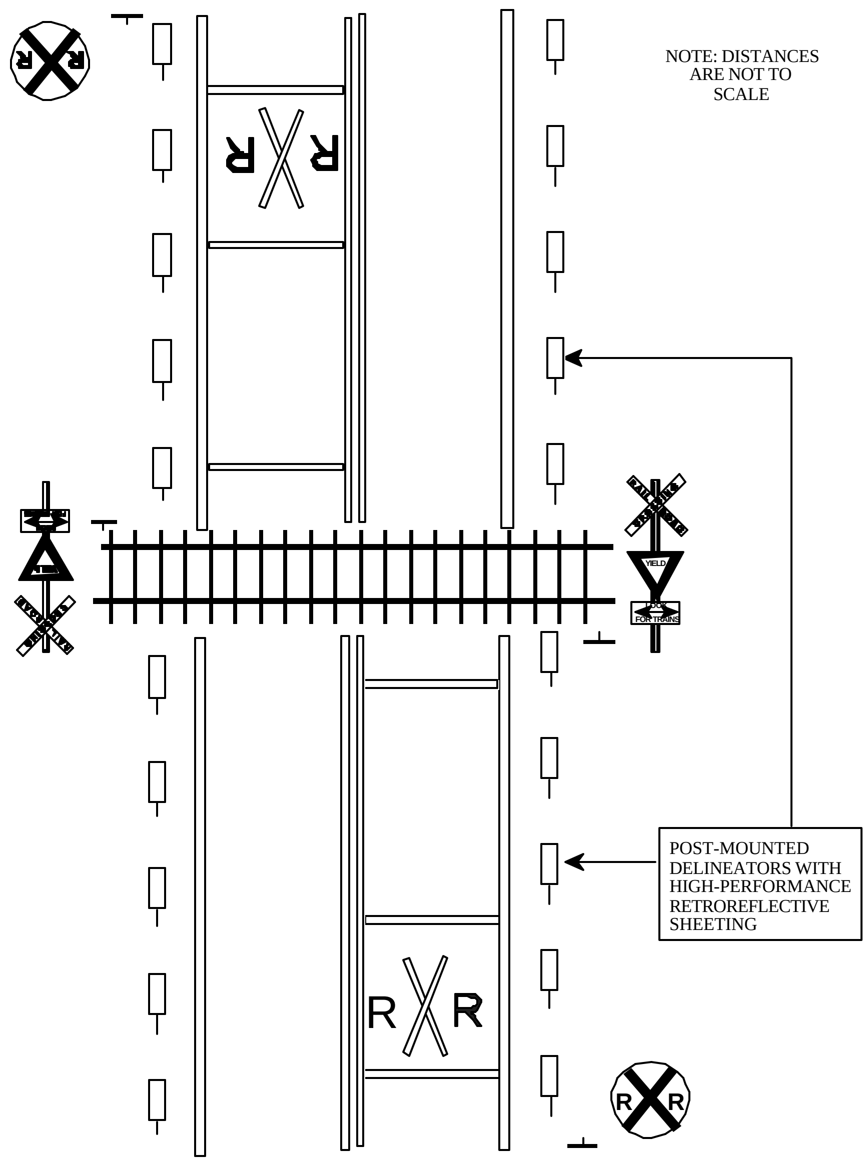
RLH:4
RRX:4
MUTCD:4

(2) Where crash experience or engineering study has determined a need for nighttime illumination as a safety countermeasure, it is recom-mended that full or semi-cutoff luminaires be used, aligned toward the track instead of toward the roadway geometry.

Design Element: Passive Crossing Control Devices (Continued)

RRX:4

(3) For rural grade crossings that are not illuminated, it is recommended that the approach be delineated with post-mounted delineators spaced 15 m (50 ft) or closer together on the right shoulder, from the location of the Railroad Advance Warning sign (W10-1) to the crossbuck, and extending an equal distance beyond the crossbuck (as shown below).



SUPPLEMENTAL TECHNICAL NOTES

AGING AND DRIVER CAPABILITIES

Many aspects of sensory and cognitive function needed to drive safely deteriorate in later adulthood. In fact, recent data indicate that older adults are in the highest risk category for crashes when figures are based on crashes per number of miles driven. Among the senses, the importance of vision is paramount. To respond appropriately to all manner of stimuli in the roadway environment, a driver must first detect and recognize physical features of the roadway, traffic control devices, other vehicles, pedestrians, and a wide variety of other objects and potential hazards of a static and dynamic nature. On rare occasions, critical information concerning the presence or position of traffic is conveyed to a road user solely through an auditory signal; in the vast majority of cases, however, the visual system is preeminent at this (input) stage of processing.

Age-related changes in the lens of the eye, combined with pathology (for example, glaucoma, cataracts, diabetic retinopathy, and macular degeneration) result in the diminished capabilities that are described below.

Reductions in Acuity

This is the ability needed to discriminate high-contrast features; it is necessary for reading information on road signs. Visual acuity of 20/40 with or without corrective lenses for both eyes or one blind eye is the predominant minimum standard for driver licensing for passenger car drivers throughout the United States. However, there are an increasing number of States (including Pennsylvania, Maryland, New Jersey, Florida, Illinois, and others) that will grant a restricted license to low-vision drivers with acuities as poor as 20/70 to 20/100. Restrictions may include daytime only, area, and speed limitations. Added to reductions in acuity, aging is also associated with yellowing of the eyes' lenses and increased density (or thickening). This affects the way color is perceived and also reduces the amount of light that reaches the retina, which makes seeing in low light conditions more difficult.

Reductions in Contrast Sensitivity

This is the ability needed to detect low-contrast features; it is necessary, for example, to see worn lane lines, to detect (non-retroreflectorized) curbs and median boundaries, and to see other road users at dusk. Some people have 20/20 acuity but still have "cloudy" or washed-out vision. Contrast sensitivity makes it possible to distinguish an object from its background. It begins to decline after about age 40, as a result of normal aging. Individuals age 61+ have an increasing risk for the development of cataracts and other sight-threatening or visually disabling eye conditions that reduce contrast sensitivity. Many people with reductions in contrast for licensing sensitivity are not aware that their vision is impaired, and contrast sensitivity is not a standard test in most DMVs for licensing.

Reductions in Visual Field

This is the ability to see objects in the periphery, it is necessary for detecting signs, signals, vehicles, pedestrians, cyclists, etc., outside of a limited field of view directly ahead. A limitation in visual field size is a physiological limitation—the person's visual system is not capable of detecting a stimulus outside of his or her visual field.

Restrictions in the Area of Visual Attention

This is the ability to see potential conflicts in the periphery, and to discriminate relevant from irrelevant information; it is necessary for responding quickly and appropriately to a constantly changing traffic scene. Sometimes termed "useful field of view," "functional field of view," or "attentional window," this refers to a subset of the total field of view. Restrictions in the area of visual attention can lead to "looked but didn't see" crashes, where stimuli can be detected, but cannot be recognized and understood sufficiently to permit a timely driver response. As such, this term represents a limitation at the attentional stage of visual information processing, rather than a physiological limitation.

Increased Sensitivity to Glare

This refers to the ability to see in the presence of oncoming headlights, at night, or in the presence of sun glare in daytime. Glare introduces stray light into the eye; it reduces the contrast of important safety targets.

Slower Dark Adaptation

This is the ability needed to see targets when moving from areas of light to dark, which may occur at highway interchanges or when moving from commercialized areas to non-commercialized areas.

Decreased Motion Sensitivity

This ability is needed to accurately estimate closing speeds and distances; it is necessary, for example, for judging gaps to safely perform left turns at intersections with oncoming traffic, to cross an intersecting traffic stream from a minor road or driveway, or to merge with traffic.

Compounding the varied age-related deficits in visual performance that are a part of normal aging, an overall slowing of mental processes occurs as individuals continue to age into their seventies and beyond. Declines have been demonstrated in a number of specific mental activities that are related to driver and pedestrian safety, such as attentional, decisional, and response-selection functions. These are described below.

Selective Attention

This refers to the ability to filter out less critical information and continuously re-focus on the most critical information (for example, detecting a lane-use restricted message on an approach to a busy intersection; detecting a pedestrian crossing while watching oncoming traffic to locate a safe gap).

Divided Attention

This refers to the ability to perform multiple tasks simultaneously and process information from multiple sources (for example, lane-keeping, reading signs, noticing traffic signals and changing phases, while maintaining a safe headway with other traffic during an intersection approach).

Perception-Reaction Time (PRT)

This is the time required to make a decision about what response is appropriate for specific highway design elements and traffic conditions, and then make a vehicle control movement such as steering and/or braking. As the overall speed of mental processing of information slows with aging, PRT increases. As the complexity of the driving situation increases, PRT increases disproportionately for older motorists.

Working Memory

This refers to the ability to store, manipulate, and retrieve information for later use while driving (for example, carrying out a series of navigational instructions while negotiating in heavy traffic; or remembering, integrating, and understanding successive phases of a changeable message sign).

Finally, it has been well established that physical capabilities decline as a function of age and also as a function of general health. Aging (as well as disease and disuse) brings about changes in the components and structure of the cartilage near the joints, underlying bones, ligaments, and muscles. These changes impair the ability of the musculoskeletal system to perform driving acts. The physical capabilities (motor functions) needed for safe and effective vehicle control are described below.

Limb Strength, Flexibility, Sensitivity, and/or Range of Motion

These abilities are needed to quickly shift (the right foot) from accelerator to brake pedal when the situation demands, and apply correct pressure for appropriate speed control. They also are needed for arm movements to safely maneuver the car around obstacles.

Head/Neck and Trunk Flexibility

A key ability of a driver is to rapidly glance in each direction from which a vehicle conflict may be expected in a given situation; this includes the familiar "left-right-left" check before crossing an intersection, as well as looking over one's shoulder before merging with traffic or changing lanes.

DRIVER LICENSE RENEWAL REQUIREMENTS

State license renewal requirements for passenger car drivers in the United States are presented below. Many States allow mail-in license renewal, although a subset of these prohibit mail-in renewals for drivers over a certain age. On the other extreme, Florida requires in-person renewal at *every third cycle*, which means that a driver with a clean record will not step foot into a DMV for 18 years (or 12 years for an unclean record). Petrucelli and Malinowski (1992) state that "the examiner's personal contact with the applicant is the only routine opportunity to detect potential problems of the functionally impaired driver." There are also differences in license renewal testing requirements (vision, written knowledge, and on-road driving) across the United States. General visual acuity requirements for driver licensing are included in this table; however, most States also have a visual field requirement that is not included in this table. Specific driver licensing requirements may be obtained by accessing each State's Department of Motor Vehicles website.

State	2001 Licensing Renewal Requirements and Distinctions for Older Drivers
Alabama	4-year renewal cycle (in-person). No tests for renewal. Minimum acuity 20/60 in one eye with/without corrective lenses. May not use bioptic telescopic lens to meet acuity standard. **No special requirements for older drivers.**
Alaska	5-year renewal cycle (mail-in every other cycle). No renewal by mail for drivers age 69+ and to drivers whose prior renewal was by mail. Vision test required at in-person renewal. Minimum 20/40 in one eye for unrestricted license. 20/40 to 20/100 needs report from eye specialist; license request determined by discretion. May use bioptic telescopic lens under certain conditions.
Arizona	12-year renewal cycle. At age 65, reduction of interval to 5 years. New photograph and vision test at renewal; no renewal by mail after age 70 (available to active duty veterans and dependents only). Minimum acuity 20/40 in one eye required; acuity of 20/60 restricted to daytime only. May not use bioptic telescopic lens to meet acuity standard.
Arkansas	4-year renewal cycle. Vision test required at renewal, with minimum 20/40 required for unrestricted license. Acuity of 20/60 restricted to daytime only. Bioptic telescopes permitted under certain circumstances. **No special requirements for older drivers.**
California	5-year renewal cycle with vision test and written knowledge test required. No renewal by mail at age 70. Minimum visual acuity is 20/200 (best corrected) in at least one eye, as verified by an optometrist or ophthalmologist. Bioptic lenses are permitted for driving, but may not be used to meet 20/200 acuity standard.
Colorado	5-year renewal cycle (mail-in every other cycle). Vision test required at renewal. Minimum acuity must be 20/70 in the better eye if worse eye is 20/200 or better; 20/40 if worse eye is worse than 20/200. Bioptic telescopes are permitted to meet acuity standard. No renewal by mail for drivers age 65+.

State	2001 Licensing Renewal Requirements and Distinctions for Older Drivers
Connecticut	4-year renewal cycle (mail-in every other cycle). Vision test required at in-person. 20/40 required in better eye for unrestricted license; 20/50 to 20/70 restricted license; under some circumstances, a license may be issued when acuity is 20/200. No license may be issued to drivers using telescopic aids. Reduction of interval to 2 years may be requested by drivers age 65+.
Delaware	5-year renewal cycle (in-person). No tests required for renewal. Minimum acuity 20/40 for unrestricted license; restricted license at 20/50; beyond 20/50 driving privileges denied. Bioptic telescopes treated on case-by-case basis. **No special requirements for older drivers.**
District of Columbia	4-year renewal cycle (in-person). Unrestricted license for 20/40 acuity; 20/70 in better eye requires 140° visual field for restricted license. At age 70, vision test required and physician signature attesting to physical and mental capability to drive; a medical report plus reaction test may also be required. At age 75 written knowledge and road tests may be required.
Florida	6-year renewal cycle for clean driving record; 4-year renewal cycle for unclean record. In-person renewal required every 3rd cycle. Vision test at in-person renewal. Must have 20/70 in either eye with or without corrective lenses. Monocular persons need 20/40 in fellow eye. Bioptic telescopes are not recognized to meet acuity standard. **No special requirements for older drivers.**
Georgia	4-year renewal cycle (in-person). Vision test required for renewal (within prior 6-month period). Acuity 20/60 in either eye with or without corrective lenses. Bioptic telescopes permitted for best acuity as low as 20/200, with restrictions. **No special requirements for older drivers.**
Hawaii	6-year renewal cycle for drivers ages 18 to 71 (in-person). Vision test required, with 20/40 standard for better eye. Bioptic telescopes permitted for driving, but not for passing vision test. Reduction of interval to 2 years for drivers age 72+.
Idaho	4-year renewal cycle (mail-in every other renewal). Vision test required: 20/40 in better eye for no restrictions; 20/50 - 20/60 requires annual testing; 20/70 denied license. Use of bioptic telescopes is acceptable, but acuity must reach 20/40. Driving test may be required if examiner thinks it is needed. No renewal by mail after age 69.
Illinois	4-year renewal cycle for ages 21 to 80 (mail-in every other cycle for drivers with clean records and no medical report review requirements). Vision test at in-person renewal: 20/40 in better eye for no restrictions; 20/70 in better eye results in daylight only restriction. May have 20/100 in better eye and 20/40 through bioptic telescope. Written test every 8 years unless clean driving record. From ages 81 to 86, reduction of interval to 2 years. At age 87, reduction of interval to 1 year. No renewal by mail, vision test required, and on-road driving test required at age 75+.
Indiana	4-year renewal cycle (in-person). Vision screening at renewal, including acuity and peripheral vision. 20/40 in better eye for no restriction; restricted license for 20/50. Bioptic telescope lenses permitted for best acuity as low as 20/200, with some restrictions, if 20/40 achieved with telescope. At age 75 renewal cycle reduced to 3 years. (Mandatory drive test for persons age 75+ eliminated 1/19/00). Drive test required for persons with 14 points or 3 convictions in 12-month period.
Iowa	Renewal cycle of 2 years or 4 years at driver's option. Vision screening at renewal: 20/40 in better eye, with or without corrective lenses; 20/50 in better eye results in restricted license for daylight only; 20/70 in better eye results in restricted license for daylight only up to 35 mi/h. Bioptic telescopes are not permitted to meet acuity requirement. At age 70, renewal cycle is 2 years.
Kansas	6-year renewal cycle for ages 16-64 (in-person). Vision and knowledge test at renewal. Minimum acuity: 20/40 better eye; 20/60 better eye with doctor report; worse than 20/60 must demonstrate ability to operate vehicle safely and have safe record for 3 years. At age 65, renewal every 4 years.

State	2001 Licensing Renewal Requirements and Distinctions for Older Drivers
Kentucky	4-year renewal cycle (in-person). No tests required for renewal. Minimum visual acuity 20/200 or better with corrective lenses in better eye; 20/60 or better using a bioptic telescopic device. **No special requirements for older drivers.**
Louisiana	4-year renewal cycle (mail-in every other cycle). Vision test at renewal. Minimum acuity 20/40 in better eye for unrestricted; 20/50 - 20/70 with restrictions; 20/70 - 20/100 possible restricted license; less than 20/100 in better eye - referred to Medical Advisory Board (MAB). No renewal by mail to drivers over age 70, or those with a conviction of moving violation in 2-year period prior to renewal.
Maine	6-year renewal cycle. At age 65, renew every 4 years. Vision screening test at renewal for age 40, 52, and 65; every 4 years after age 65. Minimum acuity 20/40 better eye without restrictions; 20/70 better eye with restrictions.
Maryland	5-year renewal cycle. Vision tests required for renewal (binocular, acuity, peripheral). Minimum acuity of at least 20/40 plus continuous field of vision at least 140° in each eye for unrestricted license; at least 20/70 in one or both eyes for restricted, but requires continuous field of view of at least 110° with at least 35° lateral to the midline of each side; 20/70-20/100 requires special permission from MAB. Medical report required for new drivers over age 70. (Maryland law specifies that age alone is not grounds for re-examination of older drivers.)
Massachusetts	5-year renewal cycle (in-person). Vision screening at renewal: 20/40 better eye for unrestricted; 20/70 better eye for restricted; 20/40 through telescope, 20/100 through carrier. **No special requirements for older drivers**. (Massachusetts law prohibits discrimination by reason of age for licensing issues.)
Michigan	4-year renewal cycle (mail-in every other cycle if free of convictions). Vision and knowledge test at renewal. Minimum acuity 20/40 better eye for unrestricted; 20/70 better eye with daylight only restriction; 20/60 if progressive abnormalities or diseases of the eye. **No special requirements for older drivers.**
Minnesota	4-year renewal cycle. Vision test at renewal: 20/40 in better eye for no restrictions; 20/70 in better eye for speed limit restrictions; 20/100 better eye referred to driver evaluation unit. **No special requirements for older drivers.** (Minnesota law specifies that age alone is not justification for reexamination.)
Mississippi	4-year renewal cycle (in-person). Vision test at renewal: 20/200 best corrected without telescope; 20/70 with telescope. **No special requirements for older drivers.**
Missouri	3-year renewal cycle (in-person). Vision test and traffic sign recognition test required at renewal. Minimum acuity: 20/40 in better eye for unrestricted; up to 20/160 for restricted. **No special requirements for older drivers.**
Montana	8-year renewal cycle for ages 21-67. Vision test at renewal: 20/40 in better eye for no restrictions; 20/70 in better eye with restrictions on daylight and speed; 20/100 in better eye possible restricted license if need is shown. For ages 68-74, renewal cycle reduced to 1-6 years. At age 75, renewal cycle reduced to 4 years.
Nebraska	5-year renewal cycle. Vision test at renewal: Knowledge test if violations on record. Acuity 20/40 required in better eye, but 17 restrictions are used, depending on vision in each eye. **No special requirements for older drivers.**
Nevada	4-year renewal cycle (mail-in every other cycle, if qualified). Minimum acuity 20/40 in better eye. Bioptic telescopes permitted to meet acuity standard: 20/40 through telescope, 20/120 through carrier, 130° visual field. Vision test and medical report required to renew by mail at age 70.
New Hampshire	4-year renewal cycle (in-person). Vision test at renewal: 20/40 better eye for unrestricted; 20/70 in better eye with restrictions. At age 75, road test required at renewal.

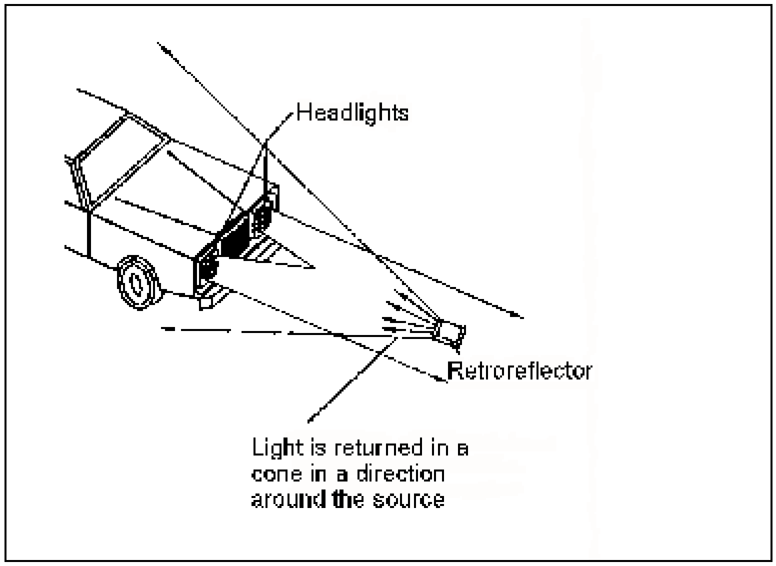
State	2001 Licensing Renewal Requirements and Distinctions for Older Drivers
New Jersey	4-year renewal cycle (10-year in person digitized photo licenses will be implemented in 2003). Periodic vision retest: 20/50 better eye; 20/70 in better eye with restrictions. Bioptic telescope permitted to meet acuity standard. **No special requirements for older drivers.**
New Mexico	4- or 8-year renewal cycle. Drivers may not apply for 8-year license if they will reach the age of 75 during the last 4 years of the 8-year period. Vision test required for renewal; knowledge and driving test may be required. Minimum acuity: 20/40 better eye; 20/80 better eye with restrictions.
New York	5-year renewal cycle. No tests for renewal. Minimum best corrected acuity 20/40 in one eye; 20/40 - 20/70 best corrected one eye requires minimum 140° horizontal visual field; 20/80 - 20/100 best corrected in one eye requires minimum 140° horizontal visual field plus 20/40 through bioptic telescopic lens. **No special requirements for older drivers.**
North Carolina	5-year renewal cycle (in-person). Vision and traffic sign recognition tests required for renewal. Acuity 20/40 in better eye required for unrestricted; 20/70 better eye with restrictions. Bioptic telescopes are not permitted for meeting acuity standard, but are permitted for driving. **No special requirements for older drivers.**
North Dakota	4-year renewal cycle. Vision test required for renewal: 20/40 better eye for unrestricted; 20/70 in better eye with restrictions. Bioptic telescopes permitted to meet acuity standard: 20/130 in carrier, 20/40 in telescope, full peripheral field. **No special requirements for older drivers.**
Ohio	4-year renewal cycle. Vision test required for renewal: 20/40 better eye for unrestricted; 20/70 better eye with restrictions; bioptic telescopes permitted to meet acuity standards. **No special requirements for older drivers.**
Oklahoma	4-year renewal cycle (in person). No tests for renewal. Minimum acuity: 20/40 better eye for unrestricted; 20/100 better eye with restrictions. Bioptic telescopes not permitted to meet acuity standard, but may be used for driving. **No special requirements for older drivers.**
Oregon	8-year renewal cycle (mail-in every other cycle). Vision screening test once every 8 years at age 50+. Minimum acuity: 20/40 better eye for unrestricted; 20/70 better eye with restrictions. Bioptic telescopes not permitted to meet acuity standard, but may be used for driving.
Pennsylvania	4-year renewal cycle. Drivers age 65+ may renew every 2 years. Random physical examinations for all drivers age 45+; most selected are over age 65. Minimum acuity: 20/40 better eye for unrestricted; up to 20/100 combined vision with restrictions. Bioptic telescopes not permitted to meet acuity standards, but may be used for driving.
Rhode Island	5-year renewal cycle. Vision test required for renewal: 20/40 better eye. At age 70, renewal cycle reduced to 2 years.
South Carolina	5-year renewal cycle (in-person). Renewal by mail if no violations in past 2 years, and license is not suspended, revoked, or canceled. Vision test and knowledge test required if > 5 points on record. Minimum acuity: 20/40 better eye for unrestricted; 20/70 in better eye if worse eye is 20/200 or better; 20/40 if worse eye is worse than 20/200. Bioptic telescopes not permitted to meet acuity standard, but may be used for driving. **No special requirements for older drivers.**
South Dakota	5-year renewal cycle. Vision test required for renewal: 20/40 better eye for unrestricted; 20/60 better eye with restrictions. **No special requirements for older drivers.**
Tennessee	5-year renewal cycle (mail-in every other cycle). Minimum acuity: 20/30 better eye; 20/70 better eye with restrictions; 20/200 better eye requires bioptic telescopes with 20/60 through the telescope. Bioptic telescopes are permitted to meet standard. No tests required for renewal. **No special requirements for older drivers.**
Texas	6-year renewal cycle (effective 01/01/02; staggered 4 to 6 years until 2002). Vision test required for renewal: 20/40 better eye; 20/70 better eye with restrictions. Bioptic telescopes are permitted to meet acuity standard, and driver must pass a road test. **No special requirements for older drivers.**

State	2001 Licensing Renewal Requirements and Distinctions for Older Drivers
Utah	5-year renewal cycle (mail-in every other cycle if: no suspensions, no revocations, no convictions for reckless driving, and no more than 4 reportable violations). Vision test required for drivers age 65+, every renewal. Minimum acuity: 20/40 for unrestricted; 20/100 in better eye with restrictions. Bioptic telescopes are not permitted to meet acuity standard.
Vermont	2-year or 4-year renewal cycle. Minimum acuity: 20/40 in better eye; bioptic telescopes are permitted to meet visual acuity standard, and driver must pass road test. No tests for renewal. **No special requirements for older drivers.**
Virginia	5-year renewal cycle (mail-in every other cycle unless suspended or revoked, 2+ violations, seizures/blackouts, DMV medical review indicator on license, failed vision test). Vision test required for renewal. Minimum acuity: 20/40 better eye for unrestricted; 20/200 with restrictions; bioptic telescopes are permitted with 20/200 through carrier, 20/70 through telescope. Knowledge and road test required if 2+ violations in 5 years. **No special requirements for older drivers.**
Washington	4-year renewal cycle (in-person). Vision test required for renewal. Minimum acuity 20/40 better eye; 20/70 better eye with restrictions. Bioptic telescopes are permitted to meet acuity standards. Other tests may be required if License Service Representative deems it necessary. **No special requirements for older drivers.**
West Virginia	5-year renewal cycle. Minimum acuity: 20/60 better eye; if worse than 20/60, optometrist or ophthalmologist must declare ability to be safe. Bioptic telescopes are not permitted to meet acuity standard, but may be used for driving. No tests required for renewal. **No special requirements for older drivers.**
Wisconsin	8-year renewal cycle. Minimum acuity: 20/40 better eye; 20/100 better eye with restrictions. Bioptic telescopes are not permitted to meet acuity standards, but may be used for driving. Vision test required for renewal. No renewal by mail at age 70+.
Wyoming	4-year renewal cycle (mail-in every other cycle). Vision test required for renewal (for both mail-in and in person). Minimum acuity; 20/40 better eye; 20/100 better eye with restrictions. Bioptic telescopes are permitted to meet acuity standard. **No special requirements for older drivers.**

MEASURING THE VISIBILITY OF HIGHWAY TREATMENTS

The visibility of highway treatments providing guidance information to motorists is critical, particularly for nighttime operations. Guidance information is needed sufficiently in advance of any change in roadway heading, to allow the driver to plan and execute steering and speed control movements smoothly as needed for path maintenance. Taking into account the diminished visual, attentional, and perceptual-cognitive abilities associated with normal aging as documented in the *Highway Design Handbook for Older Drivers and Pedestrians*, a 5-s preview distance (at operating speeds) is regarded as the *minimum* for which visibility requirements should be established, and for high-speed operations a preview distance or 7 to 10 seconds or more may be advisable.

Treatments rendered visible by reflected light include all non-internally illuminated targets, such as pavement markings, raised pavement markers, vertical (post-mounted) delineators, and



highway signs. At nighttime, these treatments are illuminated by vehicle headlights, and light is returned (reflected) principally back in the direction of the driver's eye. As illustrated in the drawing to the right, this property denotes the characteristic of *retroreflectivity*. According to the *MUTCD*, markings that must be visible at night should be retroreflective unless ambient illumination ensures adequate visibility. The recommendations contained within the *Highway Design Handbook for Older Drivers and Pedestrians* are intended to improve the visibility of retroreflectorized pavement markings used to delineate lane and roadway boundaries, curbs, medians, and other raised surfaces, and to channelize traffic in the vicinity of intersections.

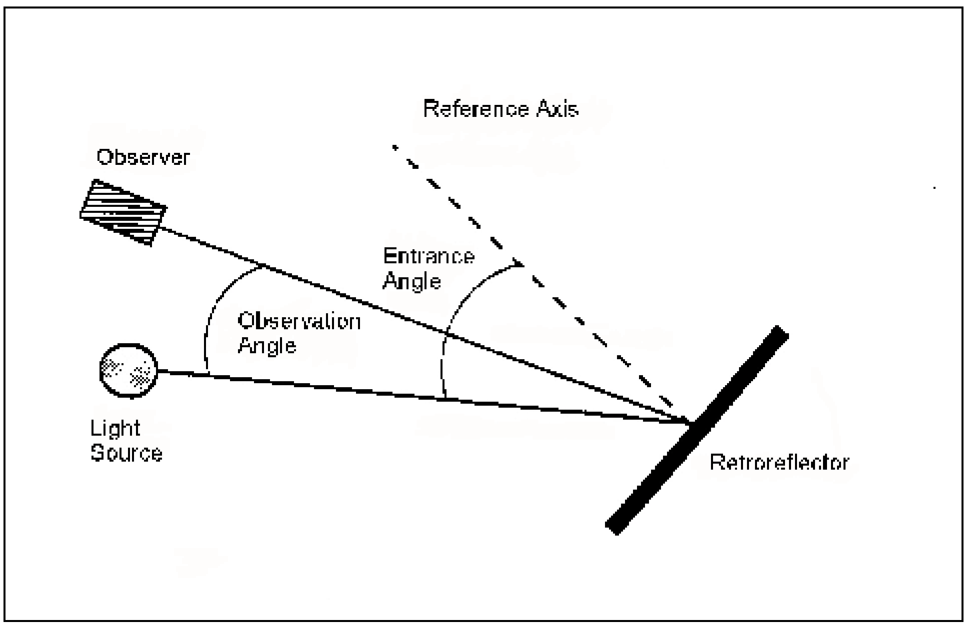
General principles of retroreflection, as well as driver visibility needs, are discussed at length in the FHWA *Roadway Delineation Practices Handbook* (Migletz, Fish, and Graham, 1994), and the interested reader is encouraged to consult that resource. Before turning to measurement techniques, however, several key points deserve emphasis.

First, the human visual system is capable of discriminating an object against its background only when a threshold level of *contrast* has been reached. While color contrast is important in certain contexts, it is the relative brightness of the visual target (e.g., pavement striping) against the surrounding area (the road surface) that is most critical. The brightness of an object rendered visible by reflected light is described by its *luminance* (L) level. Contrast (C) is commonly defined as the ratio of an object's luminance minus the luminance of the surrounding area, relative to the surrounding area alone, and is thus calculated according to the formula:

$$contrast\ (C) = \frac{L_{treatment} - L_{pavement}}{L_{pavement}}$$

Luminance contrast, dependent as it is on reflected light, varies according to many factors. Some relationships affecting contrast thresholds for target detection are crosscutting, however. The human visual system is less sensitive to contrast as the ambient light level decreases and the human visual system is less sensitive to contrast as a consequence of normal aging. Therefore, moving from daylight through twilight and dusk to nightfall, more contrast is required to see a given target; this increment is significantly greater for older drivers than for younger drivers. This means that the contrast of critical safety targets such as lane and road boundaries must be maintained at higher levels to accommodate the needs of older drivers, especially at night.

Considerable research has been conducted by FHWA and others to develop specifications for retroreflective materials to return sufficient light to a driver's eyes (from a target at a specified distance and angular relationship to the driver and illuminated by a specified light source) to ensure a contrast level above the threshold for detection (Ziskind, Mace, Staplin, Sim, and Lococo, 1991; Mercier, Goodspeed, Simmons, and Paniati, 1995; Zwahlen and Schnell, 1999, 2000). The retroreflective performance of pavement markings, which is a property of the materials from which they are fabricated, is measured in the (metric) units of millicandela per square meter per lux ($mcd/m^2/lx$). This measure also denotes the coefficient of retroreflected light (R_L). Higher values of R_L for a material indicate higher (installed) brightness levels when viewed by an observer/driver at a specified angular relationship with the light source and target. Two angles are key to this relationship: the angle between the light source, the observer, and the target surface and the angle between the incident light path and a reference axis normal to the surface of the target. These are labeled the *observation angle* and the *entrance angle*, respectively, as represented in the drawing below:



For entrance angles less than 30°, R_L is much more sensitive to the observation angle. The observation angle is a function of the distance a vehicle is from the target illuminated by its headlights, and the height of both the headlights and the driver's eyes above the road surface. For an assumed driver eye height of 1.45 m (57 in), headlight height of 0.61 to 0.71 m (24 to 28 in), and detection distance of approximately 80 m (260 ft) — chosen to afford a 5-s preview at a speed of 56 km/h (35 mi/h) — the observation angle is 1°. In fact, the observation angles for pavement treatments for the full range of road types and operating speeds of interest fall within a 1-degree span, from 0.5° to 1.5°. Since driver eye height and headlight position do not change, the critical variable is the preview distance at which a target must be visible to the motorist for safe vehicle control.

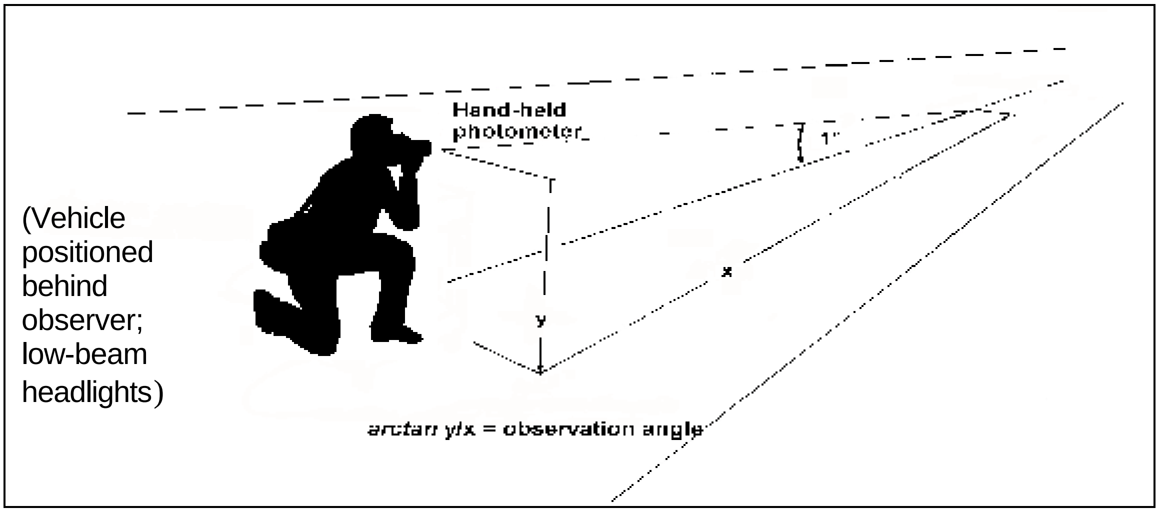
Retroreflective materials used for pavement treatments are designed to return enough light from headlight illumination to a driver under a defined viewing geometry, as noted above, that their contrast is well above threshold. Specifically, the performance requirement for a given material is defined by the amount that the contrast obtained under a set of reference viewing conditions exceeds threshold contrast. This performance requirement is confirmed through laboratory and or field measurements, using an instrument (a *retroreflectometer*) with an internal light source and a means of control over the entrance and observation angles when the instrument is applied to the to-be-measured surface. Such measurements yield the amount of light (luminance intensity) that is reflected in the desired direction. If the performance specification for the material is met, it is assumed that a level of contrast resulting in a high probability of detection will also be obtained.

Emerging retroreflectivity standards for various highway signing and marking applications from FHWA hold the promise of significantly improving the visibility of these treatments, *if* extended to include maintained levels of performance as well as a specification for performance at the time of installation. Even with this development, however, there are concerns with the measurement of retroreflectivity, concerns that are serious enough that a supplementary approach has been recommended in this Handbook.

One concern is with the required precision of measurement using a retroreflectometer. As stated above, retroreflectivity is quite sensitive to small changes in observation angle. Field experience by the Handbook authors with portable retroreflectometers indicates that adjustments in this measurement parameter can be both unreliable and unstable. The calibration of the unit also must be checked periodically to ensure valid measurements. More sophisticated, mobile measurement systems have been developed, but these are expensive and may not be available in a local jurisdiction.

Another concern with relying solely on the measurement of retroreflectivity level, is that it is a <u>mediating</u> variable from which inferences about visibility are made, rather than a <u>direct</u> measure of available contrast. The seminal FHWA study in this area concluded, "*the practical value of guidelines* [*for minimum visibility requirements for traffic control devices*] *will be determined as much as anything else by their simplicity*" (Ziskind et al., 1991). It is the contrast of the treatment, when viewed by a driver under the particular conditions of interest, that is fundamental to its visibility and probability of detection. Therefore, if it is feasible to directly measure luminance contrast, this would be a preferred practice for ensuring maintained levels of visibility to accommodate the needs of older drivers. A field methodology for such measurements is diagrammed on the following page using, as an example, an observation angle of 1°.

Using a hand-held light meter, or photometer, a technician can obtain luminance readings from a pavement treatment and from the adjacent roadway surface (background), then perform the contrast calculation shown on page 78. Several suitable instruments offering the convenience of through-the-lens aiming are commercially available at a cost of less than $3,000.



Photometric measurements should be obtained under the conditions of interest. For example, if the question is whether a treatment provides a desired level of contrast at a 5-s preview distance under low-beam headlight illumination at night, these are the conditions under which luminance measurements should be obtained. The technician operating the photometer could be located where-ever is most convenient, either in the vehicle or outside, provided that a large enough target area is viewable using the smallest aperture on the photometer. If positioned outside, as diagramed above, care should be taken not to interpose oneself directly between the light source (headlights) and the to-be-measured pavement treatment. However, because light is reflected in a cone from a given point on the retroreflective surface, the technician may move laterally a small distance and still obtain valid measurements. And because *the intensity of light reflected from the treatment (i.e., luminance) will be the same at any measurement distance*, the only essential requirement is to select x and y values using the formula *arctan y/x* that afford the desired observation angle. This means that, as one moves nearer the treatment, the photometer must be held somewhat closer to the pavement surface to preserve the observation angle. Observation angles affording a 5-s preview distance at varying speeds are:

- 1.0° at 56 km/h (35 mi/h)
- 0.8° at 72 km/h (45 mi/h)
- 0.7° at 89 km/h (55 mi/h)
- 0.6° at 105 km/h (65 mi/h)

With the information above, the vertical distance above the pavement (y) at which the photometer should be held is easily calculated for a given longitudinal separation (x) from the treatment, for a constant observation angle.

In summary, emerging retroreflectivity standards are expected to serve as a useful metric to ensure adequate visibility of highway treatments at the time of installation. It is the maintained visibility of these treatments that will most important for safe operation, however. To confirm that a sufficient level of luminance contrast to accommodate older drivers is afforded by a treatment under a specified operating condition, field measurements using the methodology outlined above are recommended.

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