

NCHRP

REPORT 600C

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

Human Factors Guidelines for Road Systems

***Collection C: Chapters 16, 17, 18, 19, 20,
22 (Tutorials 4, 5, 6), 23 (Updated),
24, 25, 26 (Updated)***

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Academies was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NCHRP REPORT 600C

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FOREWORD

By Charles W. Niessner

Staff Officer

Transportation Research Board

This report contains guidelines that provide human factors principles and findings for consideration by highway designers and traffic engineers. The guidelines allow the non-expert in human factors to more effectively consider the roadway user's capabilities and limitations in the design and operation of highway facilities.

The TRB, AASHTO, and the FHWA have been working since 2001 on two projects that together will help to promote greater safety for all road users. These two projects are the *Highway Safety Manual* (HSM) and the *Human Factors Guidelines for Road Systems* (HFG). These projects have been supported by funding from NCHRP and the FHWA. The TRB supports the *Highway Safety Manual* through the HSM Task Force and the *Human Factors Guidelines for Road Systems* through the Joint Subcommittee for the Development of a Human Factors Guideline for Road Systems.

The HSM and HFG promote improved safety for highway users and complement each other. They should be used together. Neither document is a substitute for national or state standards such as AASHTO's *A Policy on Geometric Design of Highways and Streets* or the *Manual on Uniform Traffic Control Devices*.

The HSM provides highway engineers with a synthesis of validated highway research and proven procedures for integrating safety into both new and improvement projects. It also provides practitioners with enhanced analytic tools for predicting and measuring the success of implemented safety countermeasures.

After using the HSM to develop possible design alternatives to improve safety on an in-service or planned intersection or section of roadway, the practitioner may then use the HFG to enhance the possible solutions. Successful highway safety depends on the consideration and integration of three fundamental components—the roadway, the vehicle, and the roadway user. Unfortunately, the information needs, limitations, and capabilities of roadway users are lacking in many traditional resources used by practitioners. The easy-to-use guidelines in the HFG provide the highway designer and traffic engineer with objective, defensible human factors principles and information that can be used to support and justify design decisions. The HFG will allow the non-expert in human factors to recognize the needs and limitations of the road user in a more effective manner and design roads that are safer for all.

When reviewing either existing or planned roads or intersections, highway designers and traffic engineers are strongly encouraged to use both the HFG and the HSM to identify and develop the safest solutions for road users.

NOTES ON PUBLICATION OF HUMAN FACTORS GUIDELINES FOR ROAD SYSTEMS

Chapters 16 through 20, 24, and 25; Tutorials 4 through 6 of Chapter 22; and updated Chapters 23 and 26 are contained herein. Chapters 1 through 6, 10, 11, 13, 22 (Tutorials 1 through 3), 23, and 26 were published previously. The remaining chapters are being developed under NCHRP Project 17-47 and are expected in October 2011.

Chapter 3 (Finding Information Like a Road User) and Chapter 4 (Integrating Road User, Highway Design, and Traffic Engineering Needs) are authored by Samuel Tignor, Thomas Hicks, and Joseph Mondillo.

Chapter 5 (Sight Distance Guidelines) and Tutorials 1 and 2 in Chapter 22 (Tutorials) present a revision of materials originally published as: Lerner, N., Llaneras, R., Smiley, A., and Hanscom, F. (2004). *NCHRP Web-Only Document 70: Comprehensive Human Factors Guidelines for Road Systems*. Washington, DC: Transportation Research Board.

Chapter locations and publication dates.

Chapter	Published in Report	Publication Date
1. Why Have Human Factors Guidelines for Road Systems?	600A	March 2008
2. How to Use this Document	600A	March 2008
3. Finding Information Like a Road User	600A	March 2008
4. Integrating Road User, Highway Design, and Traffic Engineering Needs	600A	March 2008
5. Sight Distance Guidelines	600A	March 2008
6. Curves (Horizontal Alignment)	600B	December 2008
7. Grades (Vertical Alignment)		Forthcoming
8. Tangent Sections and Roadside (Cross Section)		Forthcoming
9. Transition Zones Between Varying Road Designs		Forthcoming
10. Non-Signalized Intersections	600A	March 2008
11. Signalized Intersections	600A	March 2008
12. Interchanges		Forthcoming
13. Construction and Work Zones	600A	March 2008
14. Rail-Highway Grade Crossings		Forthcoming
15. Special Considerations for Urban Environments		Forthcoming
16. Special Considerations for Rural Environments	600C	July 2010
17. Speed Perception, Speed Choice, and Speed Control	600C	July 2010
18. Signing	600C	July 2010
19. Changeable Message Signs	600C	July 2010
20. Markings	600C	July 2010
21. Lighting		Forthcoming
22. Tutorials	600A,B,C	March, December 2008; July 2010
23. References	600C	July 2010
24. Glossary	600C	July 2010
25. Index	600C	July 2010
26. Abbreviations	600C	July 2010
27. Equations		Forthcoming

All published chapters are available as individual PDF files and as a consolidated PDF file on the TRB website.



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PASSING LANES

Introduction

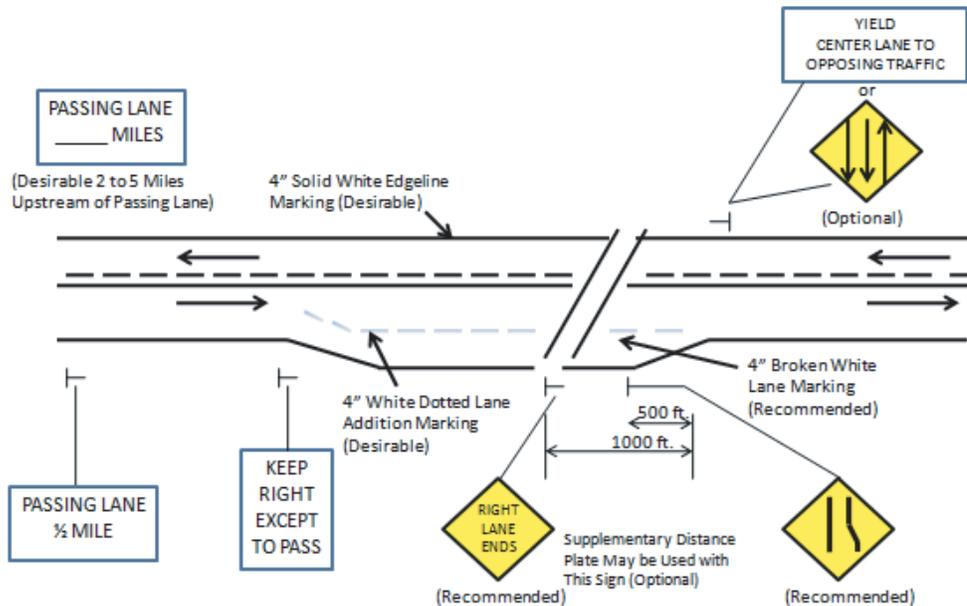
A *passing lane* is a lane added in one or both directions of travel on a two-lane, two-way highway to improve passing opportunities. This definition includes passing lanes in level or rolling terrain, climbing lanes on grades, and short four-lane sections (1). Passing lanes have been used mostly to allow drivers to bypass vehicles that are unable to maintain normal highway speeds on grades, usually called climbing lanes. Potts and Harwood (2) found that the primary benefit of passing lanes is the improvement of overall traffic operations on two-lane highways. This improved operation has direct implications for driver behavior because a driver stuck behind a slow-moving vehicle may be more likely to experience time delays and frustration, which could lead drivers to increase speeds to unsafe levels to pass a slow-moving vehicle.

Design Guidelines

RECOMMENDED VALUES OF LENGTH AND SPACING BY AVERAGE DAILY TRAFFIC (ADT) AND TERRAIN (6)

ADT (vpd)		Recommended Passing Lane Length (mi)	Recommended Distance between Passing Lanes (mi)
Level Terrain	Rolling Terrain		
≤ 1950	≤ 1650	0.8-1.1	9.0-11.0
2800	2350	0.8-1.1	4.0-5.0
3150	2650	1.2-1.5	3.8-4.5
3550	3000	1.5-2.0	3.5-4.0

TYPICAL PASSING LANE SIGNAGE AND MARKINGS (3)



Based Primarily on Expert Judgment

Based Equally on Expert Judgment and Empirical Data

Based Primarily on Empirical Data

Discussion

Two-lane highways with passing lanes provide a definite improvement in level of service over those without passing lanes (2). In particular, at medium and high volumes, a roadway with continuous alternating passing lanes can provide improvement by two levels of service over conventional two-lane highway without passing lanes. Similarly, a two-lane highway with less frequent passing lanes typically provides an improvement of one level of service over a conventional two-lane highway (2). Comparable improvements in service provided by passing lanes were found to reduce driver frustration and improve overall quality of service and the benefits of the passing lane extend beyond the confines of the added lane itself (4). Harwood, Hoban, and Warren (3) found that passing lanes improve the percentage of time drivers spend following other cars on those roads by 10% to 31% in comparison to a conventional two-lane highway without passing lanes. Passing lanes are generally well received by drivers; one study conducted in Kansas found that 93% of all respondents were positive about passing lanes and indicated a higher acceptance and satisfaction of the concept. Also, 46% of these drivers thought the passing lanes were just right in length, while 53% thought the passing lanes were too short (5). Mutabazi, Russell, and Stokes (5) also found that 88% of drivers agree more passing lanes are needed.

Highway engineers typically provide passing lanes with a primary objective of dispersing platoons and hence reducing travel time, with safety as a secondary objective. However, drivers view safety as the main benefit accrued from passing lanes (5). In the Kansas survey, 93% of drivers thought passing lanes improve safety, while 8% believed it encourages speeding. These driver perceptions are consistent with crash data analyses, which indicate that the installation of a passing lane on a two-lane highway reduces crash rates by approximately 25% (3). Harwood et al. (3) also found that crash frequency per mile per year within passing lanes sections on two-lane highways is 12% to 24% lower than for conventional two-lane highway sections.

Signage: Warning signs should be used to give drivers a preview of an upcoming passing lane and to warn drivers that the passing lane is ending. The safety and convenience benefits of passing lanes are reduced if passing lanes are not adequately signed. Clearly defined and well-maintained lane markings provide a similar function that can reduce the likelihood of drivers' selecting an oncoming lane in an attempt to enter or remain in a passing lane. In a survey of passing-lane signs, Wooldridge et al. (6) found that 61% of motorists prefer the wording "Left Lane for Passing Only" versus 29% who prefer "Keep Right Except to Pass." When surveyors reviewed the sign "Passing Lane Ahead 2 Miles," 61% of motorists would wait 2 mi to pass while the rest would pass when ready. This advance signing is useful because it also informs the driver of the repetitive nature of the passing lane design, allowing the driver to understand the purpose and nature of the roadway's characteristics. The sign should be used if the distance to the next passing lane is less than 12 mi. The sign "Right Lane End" is recommended to be located at a distance that will provide adequate notice that the passing lane is terminating.

Design Issues

Length: The effective length of the passing lane is defined as the physical length of the passing lane plus the distance downstream to the point where traffic conditions return to a level similar to that immediately upstream of the passing lane (5). Through computer stimulation, Harwood et al. (3) found the effective length to range between 4.8 km (3 mi) and 12.8 km (8 mi), depending on the physical length of the passing lane, traffic flow, traffic composition, and downstream passing opportunities.

Width and lane drop: Rinde (7) found the minimum width considered adequate for a two-lane road with a passing lane to be 40 ft. In the opinion of Rinde (7), passing should not be allowed for vehicles traveling in the single lane of three-lane roadways at traffic volumes above 3000 AADT. Also, the use of an appropriate lane-addition transition on the upstream end of a passing lane is needed for effective passing lane operations (2). The recommended length of this transition area is half to two-thirds of the length of the lane-drop taper (2).

Cross References

Signing Guidelines, 18-1

Marking Guidelines, 20-1

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COUNTERMEASURES FOR PAVEMENT/SHOULDER DROP-OFFS

Introduction

A shoulder is a portion of the roadway contiguous with the traveled way for accommodation of stopped vehicles, for emergency use, and for lateral support of the sub-base, base, and surface courses. The roadway shoulder has been recognized as desirable ever since engineers began paving roadways. However, the width, uniformity, and stability of roadway shoulders have varied greatly from roadway to roadway and along different sections of the same roadway (1). Shoulders on rural roadways serve as structural support for the surfacing and additional width for the traveled way. Shoulder drop-offs occur when there is a difference in height (ranging from a fraction of an inch to several inches) between the pavement surface and the roadside surface (2). This height difference typically arises from tire rutting erosion, excessive wear, or resurfacing. The primary concern related to drop-offs is that if they are too high, then it can pose a crash risk if a vehicle drifts outside the road and has a wheel go over the drop-off.

Design Guidelines

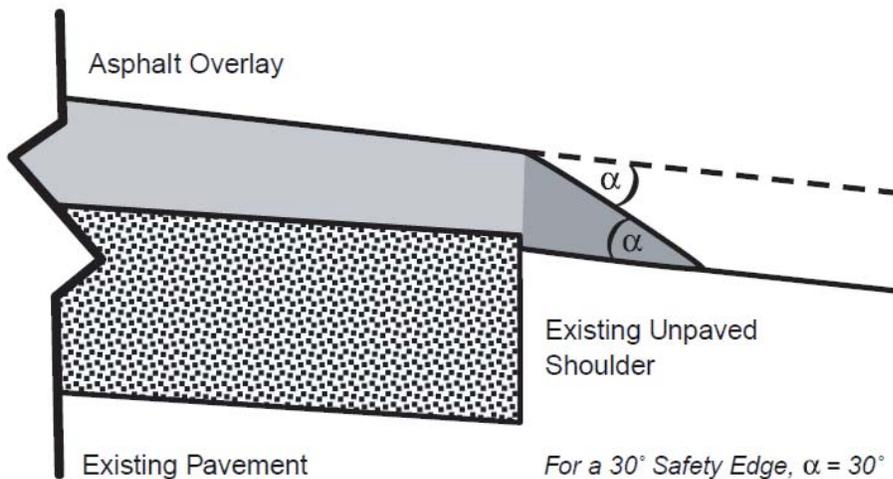
Vertical or near-vertical shoulder drop-off heights that exceed the indicated table values warrant consideration for drop-off treatment or traffic control (in work zones; adapted from Graham & Glennon (3)).

VERTICAL DROP-OFF HEIGHT WARRANTING TRAFFIC CONTROL FOR VARIOUS LANE WIDTHS

Speed (mi/h)	Drop-off Height			
	12-ft Lane Width	11-ft Lane Width	10-ft Lane Width	9-ft Lane Width
30	3 in.	3 in.	3 in.	2 in.
35	3 in.	3 in.	2 in.	1 in.
40	3 in.	2 in.	1 in.	1 in.
45	2 in.	1 in.	1 in.	1 in.
≥ 50	1 in.	1 in.	1 in.	1 in.



EXAMPLE OF SAFETY EDGE RECOMMENDED BY THE FHWA (4)



Discussion

A primary safety concern related to drop-off from the perspective of driver performance occurs when a vehicle leaves the lane and has a tire go over the drop-off (typically the front right tire). This event is often surprising and unfamiliar for most drivers, and a drop-off can interfere with their ability to return the vehicle safely to the lane. In particular, if drivers try to return to the lane at high speed and at low steering angles, their tire can “scrub” against the drop-off edge, impeding their return. A common response is to increase the steering angle towards the lane, which can lead to an abrupt change in heading once the drop-off is overcome. In severe cases, this response can result in a vehicle swerving out of the lane into the opposite-direction travel lane, putting the driver at risk of a collision with an oncoming vehicle. Motorcyclists can also have difficulties traversing drop-offs, although the vehicle control issues are somewhat different. Crash data analyses suggest that the overall frequency of crashes “probably” or “possibly” related to high drop-off is relatively low (less than 3% of rural road crashes for related road types), but that these crashes tend to result in a greater proportion of fatalities or injuries than typical rural road crashes (4).

The guideline information is primarily based on an analysis of drop-offs for work zones (3). The original source table also contained drop-off height thresholds that were higher than 3 in., but these were changed in the current guideline to reflect a more conservative assessment of other related driver performance data on driver encounters with drop-offs of various heights (4). Note that the recommendation only represents general guidance related to driver performance; other sources—such as the *Roadside Design Guide* (5)—recommend that vertical drop-offs with differentials of 2 in. or more should be avoided. What the guideline table is intended to convey is that vertical drop-off heights that exceed the listed values are more likely to be associated with increased difficulty for drivers trying to recover in a controlled manner if one of their tires go over the drop-off edge.

Another design aspect related to drop-offs that affects driver performance is the shape of drop-off. In particular, safe return to the lane is significantly more successful if a tire had to overcome a drop-off with a slope of 45° or shallower. The figure accompanying the guideline illustrates the relative “safety” of three drop-off geometries. Lane recovery with a sloped or filleted drop-off is significantly better than a straight vertical or curved drop-off. Moreover, the effectiveness of sloped drop-offs persists at higher speeds and at higher drop-off heights (4).

Design Issues

There are several accepted approaches for addressing drop-offs that are too high. For example, in work zones MUTCD warning signs for edge drop-off can notify users of present drop-off conditions. The application of a wedge-shaped asphalt material called “Safety Edge” is another possible countermeasure (see figure on previous page). When placed between the roadway and the shoulder, the material can help drivers recover from the shoulder to the driving surface. The asphalt material needs to be compacted to increase strength, otherwise the material will break apart over time due to forces and runoff water. Graham, Richard, and Harwood (6) found the results of empirical Bayes and cross-sectional analysis of sites paved with and without Safety Edge reveal that the material has a net positive effect on the safety of rural highways. Humphreys and Parham (1) found that the shoulder is best resurfaced when the roadway is resurfaced so that shoulder drop-off does not form. They also recommend that the contractor, in areas where road-resurfacing contracts must be bid separately, should be required to provide a 45° angle fillet along the edge of the roadway as part of the scope of work.

Cross References

Design Consistency in Rural Driving, 16-8

Key References

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RUMBLE STRIPS

Introduction

Shoulder rumble strips (SRS) are raised or grooved patterns on the shoulder of a travel lane intended to provide a tactile/haptic and auditory alert to drivers who stray onto the shoulder. When a vehicle’s wheels traverse an SRS, they generate both an increase in sound and haptic (physical) vibrations that drivers feel through their seat, foot pedals, floor, and steering wheel. SRSs are best suited for warning inattentive or drowsy drivers who are leaving the travelled way. SRSs can potentially wake drivers who fall asleep; however, this result typically requires a greater level of sound and vibration. In general, SRSs must produce sound and vibration levels that are easily detectable, yet not so loud and jarring that they startle drivers. The design challenge is balancing the need to provide alerts in a variety of situations (e.g., in heavy trucks or to sleeping drivers) with the need to avoid potentially undesirable startling effects and difficulties that SRSs can cause bicyclists.

Previous safety evaluations of SRSs confirm their overall effectiveness. For example, Griffith (1) indicates there is a medium-high level of predictive certainty that SRSs reduce all single-vehicle run-off-road (SVROR) crashes by 21% on rural freeways and by 18% on all freeways (i.e., both rural and urban). FHWA (2) also indicates that continuous SRSs reduce injury SVROR crashes by 7% on rural freeways and by 13% on all freeways. Rumble strips have been shown to significantly reduce the run-off-road crash rate on some rural highways by up to 80% (3).

Design Guidelines

COMMON ROADWAY SOUNDS AND ASSOCIATED DB LEVELS

SRS should produce an audible sound between 6 and 15 dB louder than background noise levels.	dB	Sound	dB	Sound
	60	Freeway driving from inside car	85	Heavy traffic
	70	Freeway traffic	90	Truck
	75-80	Inside heavy truck cab	95-100	Motorcycle
	85	City traffic inside car	110	Car horn

EFFECTS OF DIFFERENT SRS DIMENSIONS ON AUDITORY / TACTILE ALERTS

Characteristic	Suitable Values	Direct Effect on Driver	Implications for Effectiveness
Lateral placement / offset	<ul style="list-style-type: none"> 6+ in. from lane edge (but depends on other factors) 	Drivers encounter the alert sooner, the closer it is to the lane edge.	The sooner the warning occurs, the more space drivers have to recover before reaching the road edge.
Groove Width	<ul style="list-style-type: none"> 16 in. (12 may be acceptable if the shoulder is narrow) 	Wider SRS will produce sounds/vibrations for a longer duration as the vehicle laterally traverses it.	Sounds presented for longer durations are generally easier to detect.
Groove Depth	<ul style="list-style-type: none"> 7/16 in. 	Deeper grooves increase sound and vibration alert levels.	Louder sounds and vibrations are easier to detect relative to background noise levels.
Groove Separation	<ul style="list-style-type: none"> 11-12 in. 	Narrower groove separation slightly increases the frequency.	Drivers generally perceive higher tones as sounding more urgent.
Longitudinal Gaps	<ul style="list-style-type: none"> None if shoulder not shared with bikes 12 ft if shoulder shared with bikes 	Gaps of 12 ft or less can reduce the chance that a vehicle will miss the SRS completely.	Effectiveness will be lower than without gaps because alert duration will be shorter over gap sections.



Discussion

Torbic et al. (4) found that there is no conclusive evidence indicating a clear minimum level of stimulus that a shoulder or centerline rumble strip must generate in order to alert an inattentive, distracted, drowsy, or fatigued driver. However, the applicable research literature generally indicates that rumble strips that generate a 3 to 15 dBA increase above the ambient in-vehicle sound level can be detected by awake drivers. Also some evidence suggests that a sudden change in sound level above 15 dBA could startle a driver. However, a rumble strip generating more than a 15 dBA increase above the ambient sound level should not be automatically assumed to cause negative impacts (e.g., an increase in crashes), but rather to increase the potential for startling drivers who encounter the rumble strip.

Related guidance for in-vehicle warning tones typically recommends sound intensity levels for auditory-only warnings (unaccompanied by vibrations) of between 10 and 30 dB above background noise levels, while not exceeding 90 dB overall. The SRS guidelines differ significantly from the guidance for in-vehicle warning tones because of the presence of haptic vibrations with the SRS. In particular, at least for passenger vehicles, background vibration levels are low in small vehicles and even a small change in vibration can be clearly detected. Laboratory driving simulator studies show that usually drivers easily detect steering wheel or brake pedal vibrations of 1.2-1.5 Nm torque presented over half a second. In contrast to passenger vehicles, cab vibrations in heavy trucks are significant and the size and weight of heavy trucks reduce the vibrations generated by SRS; therefore, the vibration component of SRS is viewed to have minimal benefit for alerting heavy truck drivers.

It is also worth noting that the effectiveness of SRS for waking sleeping drivers has not been closely examined and that it is likely that SRS are much less effective in this application. The primary reasons for this lesser effectiveness are that greater stimulus levels are required to wake a sleeping driver rather than to merely alert a distracted or drowsy driver and that the increased arousal caused by traversing rumble strips is brief and insufficient (5).

The rationale for the “suitable values” in the guidelines table is discussed in further detail in FHWA (6), Spring (7), and Torbic et al. (4). For the most part, the values also accommodate bicycle traffic on the shoulder.

Design Issues

An important consideration when installing SRS on non-controlled-access roadways is the impact on bicyclists (and possibly motorcyclists) because several aspects that improve the alerting aspects of rumble strips (e.g., depth) also make SRS more challenging to traverse. A key factor in the suitability of a shoulder for accommodating both SRS and bicycle traffic is the shoulder width (see table below). The MUTCD (2) also recommends a 12-ft gap in 60-ft cycle, which will result in 80% coverage of the shoulder with rumble strips and exactly 1½ times cycle length for lane line stripping. Other options are to use a 40-ft cycle, consisting of a 28-ft long rumble strip with a 12-ft gap. This generally coincides with the MUTCD-recommended cycle for rural lane line markings. Both patterns should provide gaps at sufficient frequency to allow bicyclists to cross the rumble strips in advance of hazards or intersections, though the 40-ft cycle will provide gaps more frequently for a given speed.

Shoulder Width (ft)	Is there a Problem?	Reasoning
0-1.9	No	Shoulder is too narrow for SRS or bicyclists.
2-3.9	Yes	Shoulder may be wide enough for SRS or bicyclists.
4-5.9	Yes	Shoulder may be wide enough for both SRS and bicyclists.
6+	No	Shoulder is wide enough for SRS and bicyclists.

Cross References

Countermeasures for Pavement/Shoulder Drop-offs, 16-4

Key References

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DESIGN CONSISTENCY IN RURAL DRIVING

Introduction

Design consistency refers to the conformance of a highway’s geometric and operational features with driver expectancy (1). All other factors being equal, drivers will make fewer errors when faced with geometric features that are consistent with their expectations. Note that the guideline information below only provides general information about some of the factors associated with the concept of design consistency. Although research suggests that the factors listed are relevant to design consistency, at this time there is insufficient data to provide detailed quantitative recommendations.

Design Guidelines

The following driver expectancies (adapted from Lunenfeld & Alexander (2)) and factors (adapted from Fitzpatrick et al. (3)) should be considered in a design consistency review.

What is known about driver expectancies?	What factors should be considered in a design consistency review?
<ol style="list-style-type: none"> 1. Drivers tend to anticipate upcoming situations and events that are common to the road that they are traveling. 2. The more predictable the roadway, the less likely there will be driver errors. 3. Drivers experience problems when surprised or with inconsistent design or operation. 4. Drivers generally assume they will only have to react to standard situations. 5. The roadway and its environment <i>upstream</i> of a site create expectancy for <i>downstream</i> conditions. 6. Expectancies are associated with all levels of driving performance and all aspects of the driving situation. 	<ul style="list-style-type: none"> • Cross-section markings • Guide signs and route markers • Warning and regulatory signs • Geometry • Sight distance • Road type and surface • Signals • Lighting <p>Consider also:</p> <ul style="list-style-type: none"> • Land use • Terrain • Typical traffic conditions • Typical weather <p>More detailed analyses can be conducted for:</p> <ul style="list-style-type: none"> • Navigation expectancies • Guidance expectancies • Special geometric and other features



Discussion

As noted on the previous page, design consistency refers to the conformance of a highway's geometric and operational features with driver expectancy (1). In a key study leading to the development of the Interactive Highway Safety Design Model (IHSDM), crash and field data were analyzed and speed prediction models were developed for a variety of different roadway alignments (3). Four design consistency measures were associated with crash frequency:

1. Predicted speed reduction on a horizontal curve relative to the preceding curve or tangent (has the strongest and most sensitive relationship to crash frequency)
2. Ratio of an individual curve radius to the average radius for the roadway section as a whole
3. Average rate of vertical curvature on a roadway section
4. Average radius of curvature on a roadway section

Design consistency is an important concept because the driving task requires continuous/frequent:

- Sampling of visual, auditory, and haptic (touch or feel) cues
- Processing of these cues and decision making
- Outputs in the form of steering, brake, and accelerator inputs

This requirement to continuously “perceive–think–act” takes considerable effort (even when some activities become more or less automated), especially under challenging circumstances such as poor weather, nighttime conditions, heavy traffic, high speeds, etc. Inconsistent roadway design has the potential for increasing driver uncertainty about—for example—where to look for signs, how much illumination to expect from roadway section to roadway section, and how fast to drive. An inability to anticipate and predict the conditions that shape driving decisions and behaviors can lead to higher workload and, ultimately, decrements in driving performance and safety. Thus, minimizing driver workload through consistent layout and alignment of roadways is an important design goal. Although driver expectancies for a roadway can vary widely with respect to their completeness and correctness, there should ideally be a reasonable match between the geometric and operating characteristics of the rural driving environment and the driver's expectancies for this environment.

The underlying psychological factor supporting the need for design consistency is the notion of mental models or schemas (see Gentner & Stevens (4)), which—broadly defined in the context of system design—is the user's internal understanding and representation of an external reality. In the driving environment, one type of mental model is the driver's understanding of the roadway and the surrounding infrastructure, how the roadway system works, and how to operate within it. A key aspect of mental models is that they allow the driver to predict the outcome of his or her driving behaviors.

Design Issues

The IHSDM is a suite of software analysis tools for evaluating safety and operational effects of geometric design decisions on two-lane rural highways. IHSDM is a decision support tool that checks existing or proposed two-lane rural highway designs against relevant design policy values and provides estimates of a design's expected safety and operational performance. FHWA's website for the IHSDM can be found at <http://www.tfhr.gov/safety/ihsdm/ihsdm.htm>.

Cross References

Speeding Countermeasures: Using Roadway Design and Traffic Control Elements to Address Speeding Problems, 17-14

Key References

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CHAPTER 17

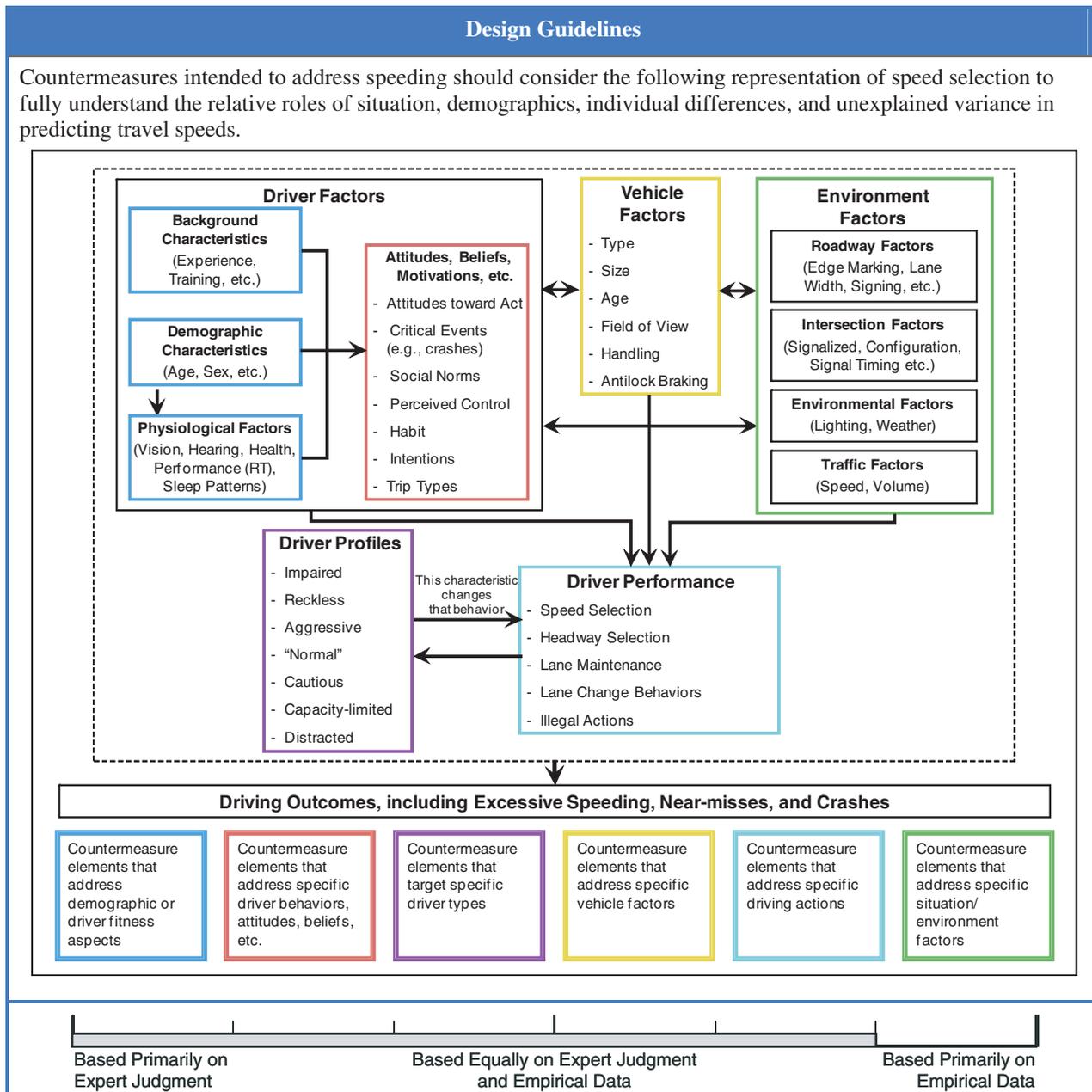
Speed Perception, Speed Choice, and Speed Control

Behavioral Framework for Speeding	17-2
Speed Perception and Driving Speed	17-4
Effects of Roadway Factors on Speed	17-6
Effects of Posted Speed Limits on Speed Decisions	17-8
Speeding Countermeasures: Setting Appropriate Speed Limits	17-10
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BEHAVIORAL FRAMEWORK FOR SPEEDING

Introduction

Behavioral framework for speeding refers to a conceptual overview of the key factors relevant to speed selection, as well as their relationship to potential speeding countermeasures. The figure below provides such a framework and attempts to capture the relevant driver, vehicle, roadway, and environment (DVRE) factors and to link these “predictor variables” to specific indices of driver behavior and driver performance. The factors and relationships depicted in the figure are firmly grounded in relevant studies and analyses of driver behavior. Specifically, it reflects past analyses and syntheses of the research literature on driver behavior and crash risk (1, 2), recent run-off-road safety work (3), safety countermeasures (4, 5), results from the recent 100-car study conducted by VTTI (6), as well as research that covers driving or crashes more generally (e.g., 7, 8, 9). Importantly, the framework includes a variety of countermeasure types, explicitly targeted at specific DVRE interactions.



Discussion

A substantial amount of research has been done on the causes of speeding and it is clear that speeding is a complex driving behavior. There is typically no single simple solution for addressing speeding concerns. The table below shows the multitude of factors that have been found to be associated with speeding or speed-related crashes. Despite all this research, there is still uncertainty regarding the relative importance of these factors and how this information can be used to develop countermeasures that effectively target specific types of drivers. The figure shown as part of the guideline on the previous page depicts how several of these factors' corresponding countermeasures are related.

FACTORS FOUND TO BE ASSOCIATED WITH SPEEDING IN PREVIOUS RESEARCH

Factor	Example Variables	Example References (see Chapter 23 for full citations)
Demographic	Age, gender, socioeconomic and education level	DePelsmacker & Janssens, 2007; Harré, Field & Kirkwood, 1996; Hemenway & Solnick, 1993; Stradling, Meadows & Beatty, 2002
Personality	Attitudes, habits, personal and social norms, thrill-seeking, beliefs	Arnett, Offer & Fine, 1997; Clément & Jonah, 1984; DePelsmacker & Janssens, 2007; Ekos Research Associates, 2007; Gabany, Plummer & Grigg, 1997; McKenna & Horswill, 2006; Stradling, Meadows & Beatty, 2002
Roadway	Posted speed	Book & Smigielski, 1999; Giles, 2004
Environment	Urban/rural	Giles, 2004; Rakauskas, Ward, Gerberich & Alexander, 2007
Vehicle	Engine size; vehicle age	Hirsh, 1986; Stradling, Meadows & Beatty, 2002
Risky Behaviors	Drinking and driving, seatbelt use, red light running	Arnett, Offer & Fine, 1997; Cooper, 1997; Gabany, Plummer & Grigg, 1997; Harré, Field & Kirkwood, 1996; Hemenway & Solnick, 1993; Rajalin, 1994
Situational	Trip time, mood, inattention, fatigue	Arnett, Offer & Fine, 1997; Ekos Research Associates, 2007; Gabany, Plummer & Grigg, 1997; Hirsh, 1986; McKenna, 2005; McKenna & Horswill, 2006

Design Issues

None.

Cross References

Speeding Countermeasures: Setting Appropriate Speed Limits, 17-10

Speeding Countermeasures: Communicating Appropriate Speed Limits, 17-12

Speeding Countermeasures: Using Roadway Design and Traffic Control Elements to Address Speeding Problems, 17-14

Key References

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SPEED PERCEPTION AND DRIVING SPEED

Introduction

Speed perception refers to a driver’s judgment of how fast he or she is traveling. While direct speed information is available from the speedometer, drivers still rely heavily on cues from the environment to judge how fast they are traveling. Auditory (engine noise) and tactile (vibrations) information can influence speed perception; however, drivers’ primary basis for estimating their speed is the visual sensation provided by the highway geometrics and other information about objects in their immediate environment streaming through their visual field. If drivers underestimate their travel speed, they are traveling faster than they expect, and if they overestimate their travel speed, they will travel slower than they expect.

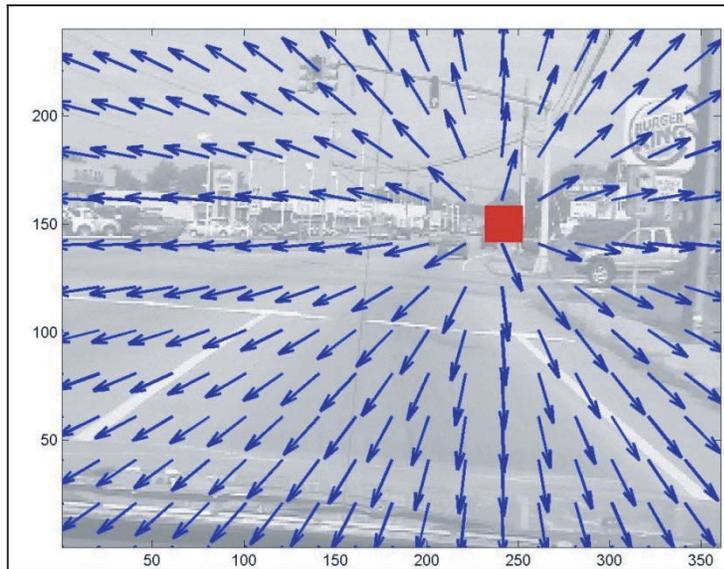
Design Guidelines

- The driver’s perceptual experience of the roadway should be consistent with intended travel speed.
- There should be some consistency between relevant roadway cues and posted speeds.

FACTORS THAT AFFECT SPEED PERCEPTION

Factors that May Cause Drivers to UNDERESTIMATE Their Travel Speed	Factors that May Cause Drivers to OVERESTIMATE Their Travel Speed
<ul style="list-style-type: none"> • Higher design standard • Greater roadway width • Divided, walled urban roads • Rural roads without roadside trees • Daylight compared to nighttime illumination conditions 	<ul style="list-style-type: none"> • Two-lane narrow urban roads • Roads densely lined with trees • Transverse pavement markings

GRAPHICAL EXAMPLE OF OPTIC FLOW FROM A CENTRAL FOCAL POINT, WHICH IS INDICATED AS THE RED BOX (FROM CNS VISION LAB (1))



Discussion

In Fildes, Fletcher, and Corrigan (2), subjects viewed film presentation of moving scenes in a laboratory setting. The study was conducted to develop a suitable means of assessing the sensory perception of speed on the road and to evaluate the effects of several road and roadside features on the speed judgments of drivers. Among other findings, the researchers reported that drivers underestimated their travel speeds on roads with higher design standards, on roads with a greater width, on divided and wide urban roads, and on rural roads without roadside trees (compared to those with many trees). They tended to overestimate their speeds on two-lane narrow urban roads.

In Triggs and Berenyi (3), subjects estimated speed under day and night conditions as passengers driving in a car on an unlit freeway. Speed was underestimated in both day and night conditions; however, judgments were more accurate at night than during the day. Importantly, centerline pavement-mounted reflectors provided a highly visible feature that was unavailable during the day.

From three types of speed estimation—(1) a driver's estimate of his/her own vehicle speed, (2) the estimation of approaching vehicle speed, and (3) detection of relative velocity when car-following—Triggs (4), a broad review of speed estimation studies, shows the following trends:

- Speed perception increases when transverse stripes are painted across the road with their separation progressively decreasing (though they may be effective only for drivers who are unfamiliar with the site).
- Speed judgments tend to be higher when a rural road is lined with trees.
- Speed judgments tend to be higher in low light conditions.
- During car-following, judgments of relative speed tend to be made more accurately when the gap between the two vehicles is closing rather than when it is opening.
- When car-following, observers in the following car tend to underestimate the relative speed difference between their car and the one in front of it.

The figure on the previous page illustrates two important sources of information that underlie drivers' speed perception. The first is the point of expansion, which is denoted by the red square, and the second is the optic flow, which is shown as the blue arrows. During forward motion, the point of expansion indicates the observers' destination and appears stationary relative to the observer. All other points are seen as moving away from the point of expansion, and the relative motion of the optic flow points forms the basis for speed perception. Points that are closer to the observer appear to move faster than points closer to the point of expansion. Stronger and more consistent optic-flow cues (e.g., dense/cluttered visual environments, salient pavement marking, etc.) can amplify the sensation of speed through the environment and cause higher speed judgments.

Design Issues

Speed adaptation, which occurs for drivers who continue at a constant speed for an extended period of time, leads to drivers generally underestimating their speed in latter sections of extended tangent sections (4). This adaptation effect has implications for design elements requiring speed changes, such as horizontal curves, because drivers may be traveling faster than expected. Additionally, this effect may also carry over to nearby roadways (5). Milosevic and Milic (6) investigated the accuracy of speed estimation in sharp curves and the effect of advisory signs on speed estimation and found that drivers with over 11 years of experience significantly underestimated their speeds.

Cross References

Behavioral Framework for Speeding, 17-2
Effects of Roadway Factors on Speed, 17-6
Effects of Posted Speed Limits on Speed Decisions, 17-8

Key References

1. CNS Vision Lab (n.d.) *Heading Perception: Where Am I Going?* Retrieved November 24, 2009 from <http://cns.bu.edu/visionlab/projects/buk/>
2. Fildes, B.N., Fletcher, M.R., and Corrigan, J.M. (1987). *Speed Perception 1: Drivers' Judgements of Safety and Speed on Urban and Rural Straight Roads*. (CR 54). Canberra, Australia: Federal Office of Road Safety.
3. Triggs, T.J., and Berenyi, J.S. (1982). Estimation of automobile speed under day and night conditions. *Human Factors*, 24(1), 111-114.
4. Triggs, T.J. (1986). Speed estimation. In G.A. Peters & B.J. Peters (Eds.), *Automotive Engineering and Litigation* (pp. 95-124). New York: Garland Press.
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EFFECTS OF ROADWAY FACTORS ON SPEED

Introduction

The *effects of roadway factors on speed* refers to the impact of geometric, environmental, and traffic factors on driving speed under free-flow conditions in tangent roadway sections. Speed in curve entry is covered in Chapter 6. Free-flowing speed is defined as conditions in which a driver has the ability to choose a speed of travel without undue influence from other traffic, conspicuous police presence, or environmental factors. In other words, the driver of a free-flowing vehicle chooses a speed that he or she finds comfortable on the basis of the appearance of the road. Typically this involves a minimum headway time of 4 to 6 s (*t*). Note that although posted speed is often found to be one of the factors that is most strongly correlated with free-flow speed, this correlation is somewhat misleading, because driver compliance with posted speed can be low if the posted speed is set too low (see the guideline “Effects of Posted Speed Limits on Speed Decisions,” on page 17-8). In contrast, the strong association between posted speed and free-flow speed typically occurs because the 85th percentile speed is often used to set the posted speed limit.

Design Guidelines

The following factors that appear to be associated with drivers’ choosing a higher travel speed should be considered when designing roadways.

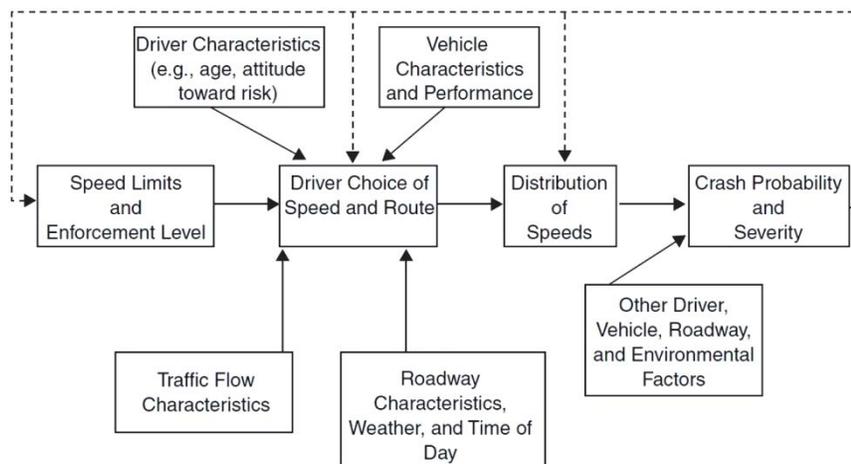
Factors Associated with HIGHER Free-Flow Speeds	Strength of Empirical Evidence	
	Rural Highways	Low-Speed Urban Streets
Higher Design Speed	Solid	Solid
Grade	Solid	Solid
Wider Lane Width	—	Mixed
Higher Access Density	Solid	Mixed
Separated Bicycle Lanes	—	Mixed
Less Pedestrian/Bicycle Side Friction	—	Mixed
No Roadside Parking	—	Mixed
Number of Lanes	Solid	—
Shoulder Width	Mixed	—



Discussion

As the table on the previous page makes clear, the empirical record is far from conclusive with respect to the ability to predict drivers' speed choices associated with relevant geometric, environmental, and traffic factors. Nonetheless, some relationships between drivers' speed choices and these factors—however tentative—have emerged from the literature and are worth presenting here. Currently, there is insufficient research to provide more quantitative guidance about how much the factors listed in the guideline table increase free-flow speed.

As seen in the figure below, roadway factors impact both the driver's choice of speed, as well as overall crash probability and severity. In Fitzpatrick, Carlson, Brewer, and Wooldridge (3), data were collected at 24 horizontal curve sites and 36 straight section sites to identify roadway factors that influence speed. Data collected included details of alignment (e.g., curve radius, curve length, straight section length), cross section (e.g., lane width, superelevation, median characteristics), roadside details (e.g., access, density, pedestrian activity), and information on traffic control devices. Laser guns were used to collect speed from vehicles at the 60 (total) sites. Multiple regression techniques, using 85th percentile speed as a "quantifiable definition of operating speed," were used in the analysis. The alignment (downstream distance to control) and cross section (lane width) factors explained about 25% of the variability in the speed data for both curve and straight road sections. Roadside factors were not significant for the straight road sections, but accounted for about 40% of the variability in the speed data for curves. Additional analyses conducted without using posted speed limits resulted in only lane width as a significant variable for straight road sections, with both median presence and roadside development as significant variables for curves.



Source: Milliken, J.G., Council, F.M., Gainer, T.W., Garber, N.J., Gebbie, K.M., Hall, J.W., et al. (2)

Design Issues

None.

Cross References

Design Consistency in Rural Driving, 16-8
Behavioral Framework for Speeding, 17-2

Key References

1. Parker, M.R., Jr. (1997). *Effects of Raising and Lowering Speed Limits on Selected Roadway Sections*. (FHWA-RD-92-084). McLean, VA: FHWA.
2. Milliken, J.G., Council, F.M., Gainer, T.W., Garber, N.J., Gebbie, K.M., Hall, J.W., et al. (1998). *Special Report 254: Managing Speed: Review of Current Practice for Setting and Enforcing Speed Limits*. Washington, DC: Transportation Research Board.
3. Fitzpatrick, K., Carlson, P., Brewer, M., and Wooldridge, M. (2001). Design factors that affect driver speed on suburban streets. *Transportation Research Record, 1751*, 18-25.

EFFECTS OF POSTED SPEED LIMITS ON SPEED DECISIONS

Introduction

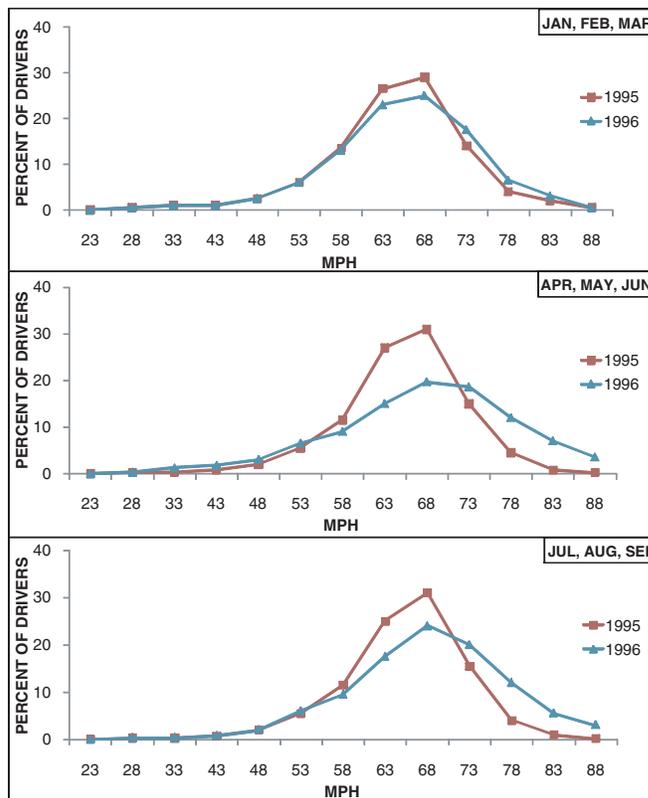
The *effects of posted speed limits on speed decisions* refers to the impact that posted speed has on actual speeds selected by drivers. This guideline covers light-vehicle driver compliance with posted speed limits on non-limited-access rural and urban highways. Drivers are legally in compliance when they are traveling at or below the posted speed limit. At a practical level, however, drivers are typically given—and they expect to be given—some small margin above the posted speed limit before being subject to law enforcement (1). Driver compliance is best assessed under free-flow conditions for a roadway segment because driver speed behavior is then largely unconstrained by external influences (e.g., traffic congestion, road work, or extreme weather) and they are free to choose their “natural” speed based on the roadway.

Design Guidelines

Posted speed limits should not be used as the only method to limit free-flow speed in light vehicles.

- For most urban and rural highways, increasing or decreasing the posted speed limits changes 85th percentile speed by approximately 1 to 2 mi/h in the same direction as the change.
- For interstate freeways, increasing the posted speed limits increases 85th percentile speed by approximately 1 to 3 mi/h. Speed dispersion also increases.

The figure below shows daytime traffic speed distributions and illustrates driver-selected speed relative to posted speed, as well as overall speed dispersion. The data are from interstate highways in Montana, both before (1995 data, 55 mi/h posted speed) and after (1996 data, at least 70 mi/h posted speed) the repeal of the National Maximum Speed Limit (NMSL) law (effective December 8, 1995).



Source: recreated from Milliken et al. (2)



Discussion

It is quite clear from both everyday observation and existing research data that most drivers do not comply with posted speed limits. In Harkey, Robertson, and Davis (3), data were collected and analyzed from 50 locations in four states to determine travel speed characteristics. The authors reported that 70.2% of drivers did not comply with posted speed limits, specifically (1) 40.8% exceeded posted speed limits by more than 5 mi/h; (2) 16.8% exceeded posted speed limits by more than 10 mi/h; and (3) 5.4% exceeded posted speed limits by more than 15 mi/h.

Milliken et al. (2) conducted a broad review of current practices in setting speed limits and provided guidelines to state and local governments on appropriate methods of setting speeds limits and related enforcement strategies. With respect to driver perceptions of speeding and speed limits, the review found that (1) most drivers do not perceive speeding as a particularly risky activity; (2) most drivers will drive at what they consider an appropriate speed regardless of the speed limit; and (3) advisory speeds have modest to little effect on driver speed, particularly for drivers who are familiar with the road. Taken together, these attitudes result in generally low compliance with posted speed.

Also from Milliken et al. (2), changing speed limits does not always result in the intended changes in behavior. Lowering the speed limits on major highways reduced both travel and speed fatalities, although driver speed compliance gradually eroded. Drivers violate new, higher speed limits because they expect the same enforcement tolerance of 5 to 10 mi/h at the higher limits. Specifically, average and 85th percentile speed typically increased 1 to 3 mi/h despite larger increases in the speed limit—a minimum of 5 mi/h. Parker (4) also found that increasing or reducing the posted speed on urban and rural non-limited access roadways did not significantly change the number of injury or fatal crashes.

Overall, changes in speed limits seem to simply legalize existing driver behavior; that is, they change compliance levels rather than speeding behavior. The findings suggest the difficulty of altering behavior merely by changing a speed sign.

As noted elsewhere, speed choices are clearly mediated by a number of factors. Milliken et al. (2) found evidence that speed enforcement is the most common mediator between speed limit and speed choice. Where speed choice is not constrained by speed limits and their enforcement, the driver does trade off travel time and safety. In an analysis of FHWA data, Uri (5) found that adherence to the 55 mi/h limit does depend on the time cost of travel, cost in terms of discomfort and irritability, enforcement and, for a subset of states, the price of gasoline.

Design Issues

One design issue to consider when changes to the posted speed limit are contemplated is the possibility of speed changes carrying over to connecting roadways. The basic idea is that drivers adapt to higher speeds on the primary road and will be biased toward driving at those higher speeds once they switch to a connecting roadway. The evidence for carryover effects is limited, especially because many studies find such a small relationship between posted speed limit change and free-flow speed on the principal roads (4, 2).

Another issue that may be worth examining in detail is the effects of speed limit changes on speed dispersion. Speed limit changes increase speed dispersion on interstate freeways, and variation in drivers' speed appears related to crash risk (2).

Cross References

Speeding Countermeasures: Setting Appropriate Speed Limits, 17-10

Speeding Countermeasures: Communicating Appropriate Speed Limits, 17-12

Speeding Countermeasures: Using Roadway Design and Traffic Control Elements to Address Speeding Problems, 17-14

Key References

1. Giles, M.J. (2004). Driver speed compliance in Western Australia: A multivariate analysis. *Transport Policy*, 11(3), 227-235.
2. Milliken, J.G., Council, F.M., Gainer, T.W., Garber, N.J., Gebbie, K.M., Hall, J.W., et al. (1998). *Special Report 254: Managing Speed: Review of Current Practice for Setting and Enforcing Speed Limits*. Washington, DC: Transportation Research Board.
3. Harkey, D.L., Robertson, H.D., and Davis, S.E. (1990). Assessment of current speed zoning criteria. *Transportation Research Record*, 1281, 40-51.
4. Parker, M.R., Jr. (1997). *Effects of Raising and Lowering Speed Limits on Selected Roadway Sections*. (FHWA-RD-92-084). McLean, VA: FHWA.
5. Uri, N.D. (1990). Factors affecting adherence to the 55 mph speed limit. *Transportation Quarterly*, 44(4), 533-547.

SPEEDING COUNTERMEASURES: SETTING APPROPRIATE SPEED LIMITS

Introduction

Setting appropriate speed limits refers to guidelines and best practices for determining appropriate speed limits that take into account the unique traffic, design, and environmental aspects of the roadway. Much of the information in this guideline, as well as its companion guidelines (“Speeding Countermeasures: Communicating Appropriate Speed Limits” on page 17-12 and “Speeding Countermeasures: Using Roadway Design and Traffic Control Elements to Address Speeding Problems,” on page 17-14), are adapted from Neuman et al. (1). As part of *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan*, the study by Neuman et al. (1) was developed to address two key problems involved in excessive or inappropriate speeds: (1) driver behavior (i.e., deliberately driving at an inappropriate or unsafe speed) and (2) driver response to the roadway environment (i.e., inadvertently driving at an inappropriate or unsafe speed, failure to change speed in a proper or timely manner, or failure to perceive the speed environment). Both these problems result in an increased risk of a crash or conflict.

Design Guidelines

The design guidelines below should be used to help set appropriate speed limits. Additional guideline information is provided in the discussion section; however, the original source of these recommendations—Neuman et al. (1)—should be consulted for more specific design guidance.

Objective	General Strategy	Design Guideline
Set appropriate speed limits	Set speed limits that account for roadway design, as well as traffic and environmental conditions	Consider the: <ul style="list-style-type: none"> Design speed of a major portion of the road, Vehicle operating speed, measured as a range of 85th percentile speeds taken from spot speed surveys of free-flowing vehicles on the roadway, Safety experience of the roadway, in the form of crash frequencies and outcomes, and Enforcement experience; i.e., law enforcement’s allowance for driving above the posted speed limit as well as the level of enforcement.
	Implement variable speed limits (VSLs)	While the efficacy of VSLs is uncertain (see also Milliken et al. (2)), they can be used for: <ul style="list-style-type: none"> Predictable events, such as during school hours and construction activities, and Unpredictable events, such as poor visibility due to fog or snow, and traffic incidents.
	Implement differential speed limits for heavy vehicles (high-speed areas only)	In high-speed areas, consider posting a lower speed limit for heavy trucks in order to reduce the severity of collisions involving trucks. <p><i>Note: Not all researchers agree that differential speed limits for trucks should be used, see the following discussion section.</i></p>



Discussion

As discussed in Neuman et al. (1), speed limits that appear inconsistent, fail to reflect the immediate roadway environment, or are inconsistent with driver expectancies may be ignored by drivers. This situation, in turn, can contribute to a lack of respect for and compliance with speed limits. The posted speed limit provides drivers with not just a legal limit, but also the maximum speed that highway engineers and road designers consider to be safe and appropriate. As noted by Milliken et al. (2), well-conceived speed limits also provide the basis for enforcement by law enforcement officers and the court system.

For the *set speed limits that account for roadway design, as well as traffic and environmental conditions* strategy, practicality and enforcement are key considerations. Setting the speed limit at the 85th percentile speed is expected to result in compliance by most drivers; however, unique design, traffic, or environmental characteristics of the roadway can also affect actual driving speeds. Such characteristics include proximity to schools or hospitals, an unusually high percentage of trucks in the traffic flow, unusually heavy pedestrian volumes, or a concentration of elderly pedestrians.

Variable speed limits (VSLs) are generally communicated through CMSs or other traffic control devices. A critical issue with VSLs is determining where they should be used, when the speed limits should be changed, and what the “other” speed limits should be; cameras or other detection equipment can be used to make these determinations (1). Visible and regular enforcement is also required to ensure compliance with the speed limits.

The use of *differential speed limits for heavy trucks* is an option for locations associated with a high incidence of truck crashes; however, the research is mixed with respect to the efficacy of doing so. The logic underlying the use of having a lower posted speed limit for trucks than for passenger vehicles is “that trucks have much longer stopping distances than do light vehicles and have other speed-related risks such as rollover at lower speeds and vulnerability to loss of control in cross winds” (3). The counterargument is that differential speed limits for trucks vs. cars increases the overall variability in vehicle speeds (at a given location at a given time), resulting in a greater potential for conflicts and crashes between trucks and cars. In a review of safety outcomes associated with heavy vehicles, Harwood, Potts, Torbic, and Glauz (4) found that the use of differential speed limits does not seem to reduce crashes, but may vary the distribution of crash types.

Design Issues

This guideline, and its companion guidelines (“Speeding Countermeasures: Communicating Appropriate Speed Limits” on page 17-12 and “Speeding Countermeasures: Using Roadway Design and Traffic Control Elements to Address Speeding Problems” on page 17-14), only include those countermeasures provided by Milliken et al. (2) that are directed at roadway design. Neuman et al. (1) should be consulted for a more detailed discussion of these countermeasures, as well as countermeasures intended (1) to heighten driver awareness of speeding-related safety issues and (2) to improve the efficiency and effectiveness of speed enforcement efforts.

Cross References

Speeding Countermeasures: Communicating Appropriate Speed Limits, 17-12
Speeding Countermeasures: Using Roadway Design and Traffic Control Elements to Address
Speeding Problems, 17-14

Key References

1. Neuman, T.R., Slack, K.L., Hardy, K.K., Bond, V.L., Potts, I., and Lerner, N. (2009). *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, Volume 23: A Guide for Reducing Speeding-Related Crashes*. Washington, DC: Transportation Research Board.
2. Milliken, J.G., Council, F.M., Gainer, T.W., Garber, N.J., Gebbie, K.M., Hall, J.W., et al. (1998). *Special Report 254: Managing Speed: Review of Current Practice for Setting and Enforcing Speed Limits*. Washington, DC: Transportation Research Board.
3. Knippling, R.R., Waller, P., Peck, R.C., Pfefer, R., Neuman, T.R., Slack, K.L., et al. (2004). *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, Volume 13: A Guide for Reducing Collisions Involving Heavy Trucks*. Washington, DC: Transportation Research Board.
4. Harwood, D.W., Potts, I.B., Torbic, D.J., and Glauz, W.D. (2003). *CTBSSP Synthesis of Safety Practice 3: Highway/Heavy Vehicle Interaction*. Washington, DC: Transportation Research Board.

SPEEDING COUNTERMEASURES: COMMUNICATING APPROPRIATE SPEED LIMITS

Introduction

Communicating appropriate speed limits refers to guidelines and best practices for communicating posted speed limits to drivers. Much of the information in this guideline, as well as its companion guidelines (“Speeding Countermeasures: Setting Appropriate Speed Limits” on page 17-10 and “Speeding Countermeasures: Using Roadway Design and Traffic Control Elements to Address Speeding Problems” on page 17-14), are adapted from Neuman et al. (1). As part of *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan*, the study by Neuman et al. (1) was developed to address two key problems involved in excessive or inappropriate speeds: (1) driver behavior (i.e., deliberately driving at an inappropriate or unsafe speed) and (2) driver response to the roadway environment (i.e., inadvertently driving at an inappropriate or unsafe speed, failure to change speed in a proper or timely manner, or failure to perceive the speed environment). Both these problems result in an increased risk of a crash or conflict.

Design Guidelines

The design guidelines below should be used to help communicate appropriate speed limits. Additional guideline information is provided in the discussion section; however, the original source of these recommendations—Neuman et al. (1)—should be consulted for more specific design guidance.

Objective	General Strategy	Design Guideline
Communicate appropriate speeds through the use of traffic control devices	Improve speed limit signage	<ul style="list-style-type: none"> Locate speed limit signs where drivers expect them to be, such as following a major intersection. Use advance notice signs (e.g., “Reduced Speed Ahead”) to alert the driver to an upcoming speed change. Consider context: where other traffic signs and/or commercial signs are abundant, use larger speed signs, increase the number of speed signs, or remove unnecessary signs.
	Implement active speed warning signs	<ul style="list-style-type: none"> Use in locations where speeding has been observed or poses a safety risk, such as school zones, sharp horizontal curves, or locations with a history of speed-related crashes.
	Use in-pavement measures to communicate the need to reduce speeds	<ul style="list-style-type: none"> May include transverse lines, peripheral transverse lines, chevron lines, and rumble strips.
	Implement changeable message signs (high-speed areas only)	<ul style="list-style-type: none"> Use CMSs to present information relevant to traffic conditions, work zones, weather and road surface conditions, detour/directional information, crashes and incidents, and appropriate speed limits.

Based Primarily on Expert Judgment

Based Equally on Expert Judgment and Empirical Data

Based Primarily on Empirical Data

Discussion

As discussed in Neuman et al. (1), information about speed limits—in the form of signs or markers—should be clearly communicated to drivers, at appropriate locations on the roadway. The posted speed limit provides drivers with not just a legal limit, but also the maximum speed that highway engineers and road designers consider to be safe and appropriate. The placement and visibility of speed signs are key to properly communicating speed limits.

Improving speed limit signage is especially important in areas where signs are frequently obscured by other signage, vegetation, or adverse weather conditions. Also, having a high percentage of older drivers on a particular section of the roadway is often a good reason to address signage location and visibility. Providing conspicuous and redundant information about unexpected posted speed changes, such as those greater than 10 mi/h, can also increase driver awareness of a speed change. This information can be provided by using “Speed Reduction Ahead” signs in advance of the change, placing signs on both sides of the roadway, and using signs with salient features (e.g., fluorescent flags) (1). Additional supplementary signs spaced every 60 s of travel (or more frequently in urban areas with increased access to the road) can also promote driver awareness of the speed limit.

Active speed warning signs improve drivers’ awareness of both their current speed and the posted speed limit in order to deter speeding behaviors. In Bloch (2), a before–after evaluation was conducted to assess the benefits of using a speed warning sign. The study found that mean speed was reduced at the sign location, but that intermittent enforcement was required to significantly reduce speeds downstream from the sign. The sign was effective in reducing excessive speeds (i.e., speeds 10 mi/h above the posted speed).

In-pavement measures and other perceptual measures can be used to encourage drivers to adhere to speed limits (1). Pavement marking—such as transverse lines, peripheral transverse lines, and chevron lines—gives the illusion that the driver is driving faster than his/her actual speed and can be used as a means to decrease excessive speeds by reducing the driver’s comfort level at higher speeds (1). These approaches can be used along any roadway segment where speed may be a problem, as well as locations where speed reductions are necessary, such as intersection approaches, work zones, toll plazas, and ramps. Rumble strips (e.g., continuous shoulder rumble strips, centerline rumble strips, or transverse rumble strips) may also be used to reduce vehicle speeds or to prevent crashes where speed is a causal factor (1). In this role, rumble strips are used as a traffic calming device in, for example, high-pedestrian areas such as parks, schools, hospitals, and residential areas. Rumble strips are also discussed in “Shoulder Rumble Strips” on page 16-6.

CMSs can also be used to display information on appropriate speeds relative to current conditions. See Chapter 19 for more details on when and how to use CMSs.

Design Issues

This guideline, and its companion guidelines (“Speeding Countermeasures: Setting Appropriate Speed Limits” on page 17-10 and “Speeding Countermeasures: Using Roadway Design and Traffic Control Elements to Address Speeding Problems,” on page 17-14), only include those countermeasures provided by Milliken et al. (3) that are directed at roadway design. Neuman et al. (1) should be consulted for a more detailed discussion of these countermeasures, as well as countermeasures intended (1) to heighten driver awareness of speeding-related safety issues and (2) to improve the efficiency and effectiveness of speed enforcement efforts.

Cross References

Speeding Countermeasures: Setting Appropriate Speed Limits, 17-10
Speeding Countermeasures: Using Roadway Design and Traffic Control Elements to Address
Speeding Problems, 17-14
Rumble Strips, 16-6

Key References

1. Neuman, T.R., Slack, K.L., Hardy, K.K., Bond, V.L., Potts, I., and Lerner, N. (2009). *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, Volume 23: A Guide for Reducing Speeding-Related Crashes*. Washington, DC: Transportation Research Board.
2. Bloch, S.A. (1998). A comparative study of the speed reduction effects of photo-radar and speed display boards. *Transportation Research Record*, 1640, 27–36.
3. Milliken, J.G., Council, F.M., Gainer, T.W., Garber, N.J., Gebbie, K.M., Hall, J.W., et al. (1998). *Special Report 254: Managing Speed: Review of Current Practice for Setting and Enforcing Speed Limits*. Washington, DC: Transportation Research Board.

SPEEDING COUNTERMEASURES: USING ROADWAY DESIGN AND TRAFFIC CONTROL ELEMENTS TO ADDRESS SPEEDING PROBLEMS

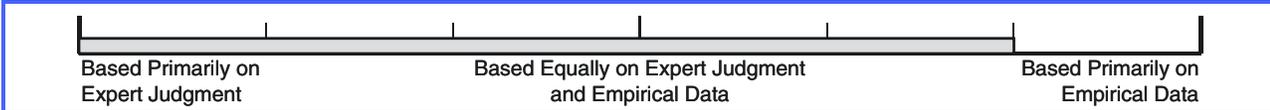
Introduction

Using roadway design and traffic control elements to address speeding problems refers to guidelines and best practices for selecting and using geometric design features and traffic signals to support safe speed decisions by drivers. Much of the information in this guideline, as well as its companion guidelines (*Speeding Countermeasures: Setting Appropriate Speed Limits* on page 17-10 and *Speeding Countermeasures: Communicating Appropriate Speed Limits* on page 17-12), is adapted from Neuman et al. (1). As part of *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan*, the study by Neuman et al. (1) was developed to address two key problems involved in excessive or inappropriate speeds: (1) driver behavior (i.e., deliberately driving at an inappropriate or unsafe speed) and (2) driver response to the roadway environment (i.e., inadvertently driving at an inappropriate or unsafe speed, failure to change speed in a proper or timely manner, or failure to perceive the speed environment). Both these problems result in an increased risk of a crash or conflict.

Design Guidelines

The design guidelines below should be used to select and use geometric design features and traffic signals to support safe speed decisions by drivers. Additional guideline information is provided in the discussion section; however, the original source of these recommendations—Neuman et al. (1)—should be consulted for more specific design guidance.

Objective	General Strategy	Design Guideline
Ensure that roadway design and traffic control elements support appropriate and safe speeds	Use consistent combinations of geometric elements to control speeds.	<ul style="list-style-type: none"> Design features such as curve radius, tangent length, length of spirals, vertical grades and curves, available sight distance, and cross-section features should be designed consistently across locations, in a manner that meets driver expectancies.
	Provide adequate change + clearance intervals at signalized intersections.	<ul style="list-style-type: none"> Clearance intervals should account for expected approach speeds and should reflect operating speeds, intersection width, vehicle lengths, and driver characteristics such as reaction time and braking. See Tutorial 4 for the equation developed by ITE (2) for determining clearance intervals.
	Provide protected left turns.	<ul style="list-style-type: none"> Implement protected-only signal phasing for left turns at high-speed signalized intersections.
	Provide improved visibility.	<ul style="list-style-type: none"> Install lighting at high-speed sections of the roadway, especially intersections.



Discussion

As discussed in Neuman et al. (1), while drivers ultimately select their own speeds, they receive, process, and use a number of cues from the immediate driving environment when doing so. Key elements of the driving environment that can effectively communicate safe speeds are roadway design and the use and operation of traffic control devices.

Design consistency is a key principle in roadway design. Using *consistent combinations of geometric elements* leads to roadway elements that meet driver expectancies and can result in consistent speeds and fewer unexpected speed changes. For example, large differences and sudden changes in horizontal alignment, available sight distance, curve radii, etc. should be avoided, as these can increase driver workload, misperceptions, errors, and—ultimately—the likelihood of crashes.

Clearance intervals provide safe transitions in right-of-way (ROW) assignment between crossing or conflicting flows of traffic. One way to accomplish safe transitions is an all-red interval, which should be designed to account for expected approach speeds to reduce the likelihood of collisions resulting from red light running. Clearance intervals that are too short can result in drivers not being able to stop in time for the red light; drivers can also stop too quickly, increasing the risk of rear-end collisions from following vehicles. Clearance intervals that are too long can lead to driver impatience, or red light running, especially in drivers familiar with the intersection. Whether the concern is red light running or increased risk of collisions, both outcomes are exacerbated by speeding.

On high-speed roadways, especially in high traffic volume situations, there may be inadequate gaps for left-turning vehicles. *Protected-only left-turn signals* have a phase designated specifically for left-turning vehicles. Other factors that may warrant the use of protected-only left-turn phases include delay, visibility, distance of the intersection, and safety at the intersection (e.g., crash history) (1). The benefits of protected-only left turns include increasing left-turn capacity and reducing intersection delays for vehicles turning left (3). The use of protected left-turn phases also improves safety by removing conflicts during a left-turn movement. This improved safety can be especially important on roadways where high operating speeds can contribute to the crash severity and may play a role in the difficulty a driver has with identifying and selecting a safe gap (1). However, the use of protected-only left-turn signals will usually increase the cycle length, which also increases delay. For additional discussion and guidance on the type of left-turn phase to use in a given situation, see Pline (4).

On high-speed roads, drivers have less time to detect visual information because vehicles are traveling faster. This problem is compounded at night when the visual contrast of some roadway elements is reduced and drivers require more time to detect visual information (drivers at higher speeds will also travel farther during this elongated detection period and consequently have less time to react to hazards). While increasing *lighting* on its own will not prevent speeding, it will make potential hazards or other important information easier for drivers to see, particularly during nighttime and adverse weather conditions.

Design Issue

This guideline, and its companion guidelines (“Speeding Countermeasures: Setting Appropriate Speed Limits” and “Speeding Countermeasures: Communicating Appropriate Speed Limits”), only include those countermeasures provided by ITE (2) that are directed at roadway design. Neuman et al. (1) should be consulted for a more detailed discussion of these countermeasures, as well as countermeasures intended (1) to heighten driver awareness of speeding-related safety issues and (2) to improve the efficiency and effectiveness of speed enforcement efforts.

Cross References

Speeding Countermeasures: Setting Appropriate Speed Limits, 17-10
Speeding Countermeasures: Communicating Appropriate Speed Limits, 17-12
Design Consistency in Rural Driving, 16-8

Key References

1. Neuman, T.R., Slack, K.L., Hardy, K.K., Bond, V.L., Potts, I., and Lerner, N. (2009). *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, Volume 23: A Guide for Reducing Speeding-Related Crashes*. Washington, DC: Transportation Research Board.
2. ITE (1994). *Determining Vehicle Signal Change and Clearance Intervals*. Washington, DC.
3. Brehmer, C.L., Kacir, K.C., Noyce, D.A., and Manser, M.P. (2003). *NCHRP Report 493: Evaluation of Traffic Signal Displays for Protected/Permissive Left-Turn Control*. Washington, DC: Transportation Research Board.
4. Pline, J.L. (1996). *NCHRP Synthesis of Highway Practice 225: Left-Turn Treatments at Intersections*. Washington, DC: Transportation Research Board.



Signing

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GENERAL PRINCIPLES FOR SIGN LEGENDS

Introduction

Sign legends refer to the text and/or symbols composing the sign message. Legends that are too long or too complicated can lead to problems in comprehension. In general, the legend on a sign must be kept to a minimum, regardless of letter size, to maximize driver comprehension.

Design Guidelines		
Type of Sign	Example (all from MUTCD (1))	Guidelines
Advance Guide		<ul style="list-style-type: none"> Limit route and destination information to a total of three lines Do not use more than two destination/street names. Place intersecting streets on top line and distance to intersecting streets on bottom.
Conventional Guide		<ul style="list-style-type: none"> Limit route and destination information to a total of three lines.
Exit Direction		<ul style="list-style-type: none"> Limit route and destination information to a total of three lines. Do not include more than two destination/street names.
Tourist		<ul style="list-style-type: none"> Place symbols to the left of the word legend. Limit information to a total of two lines.
Service		<ul style="list-style-type: none"> Limit general road user services to six.
Distance		<ul style="list-style-type: none"> Limit traffic generators to three accompanied by the related distance. Keep the highest priority distance (nearest distance) at the top or left.
Lane Control		<ul style="list-style-type: none"> Place the legend at the top of the sign.

Based Primarily on
Expert Judgment

Based Equally on Expert Judgment
and Empirical Data

Based Primarily on
Empirical Data

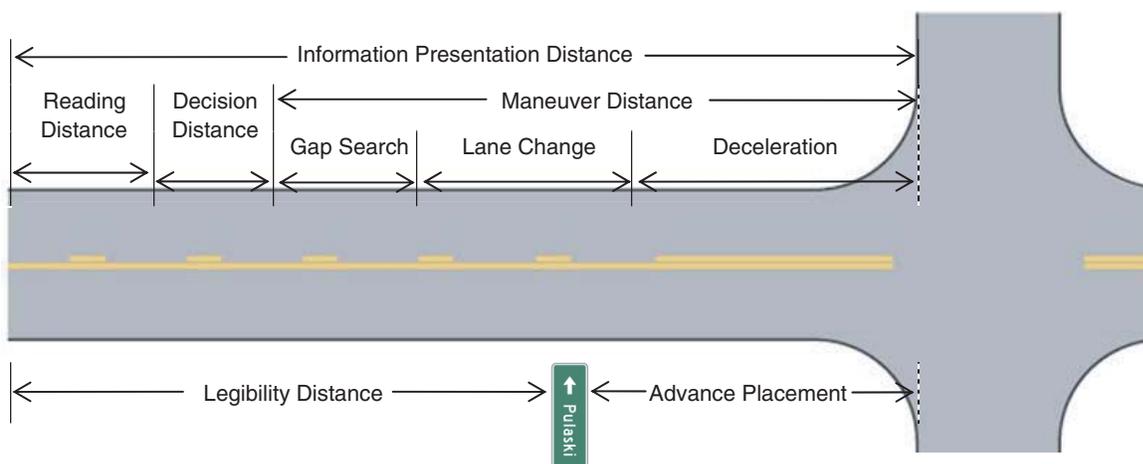
Discussion

The relatively small amount of available space on roadway signs suggests the need to make the best use of this space when designing legends. The guidelines on the previous page have been adapted from the MUTCD (1) because of their common focus on legends and because they are provided across various sections/pages within the MUTCD and can be hard to find. In general, they reflect acceptable, best practices for sign legends. The legend for a sign should be selected to maximize information transmission and comprehension, given both the nature of the sign's message and general roadway environment. Text-based signs are clearly more appropriate than symbolic signs for highly complex messages, such as destination messages or hazards that are more quickly and easily presented via text rather than potentially ambiguous or unfamiliar symbols.

There is a trade-off between the amount of information provided in a sign, the complexity of the sign information, and its overall comprehensibility. Either through the use of more words or through the use of complex graphics, the density of information presented on a sign can be increased, but often at the cost of legibility and/or comprehensibility. New sign designs (or even existing signs being used in a new location or a new way) should always be tested, using a representative group of drivers, to see if they support adequate levels of driver comprehension.

Design Issues

Sign placement and appropriate letter height are determined by a number of factors. A process for determining these values is presented in the *Traffic Control Devices Handbook* (2) and discussed in more detail in Tutorial 5. Appropriate sign placement is determined by the overall *information presentation distance*, which is the total distance at which the driver needs information about the choice point (e.g., intersection). This distance is the sum of the reading distance, the decision distance, and the maneuver distance. The reading distance is determined by the amount of time that the driver needs to read the sign's message, depending on the number of words, numbers, and symbols contained in the message. The decision distance is determined by the amount of time needed to make a choice decision and initiate a maneuver. The decision time necessary depends on the complexity of the maneuver. The maneuver distance is determined by the time necessary to complete any maneuver required by the choice. For a lane change maneuver, this distance is the sum of the gap search, lane change, and deceleration distances. These values are all influenced by the vehicle operating speed. Once the reading, decision, and maneuver distances are summed to find the information presentation distance, the advance placement distance between the sign and the choice point can be subtracted to find the *legibility distance*, which is the distance at which the sign must be legible. The required letter height can be calculated by referencing the legibility index provided in the MUTCD (30 ft/in.). When the legibility distance is divided by the legibility index, the letter height is obtained.



Cross References

Presentation to Maximize Visibility and Legibility, 19-4
Sight Distance Guidelines, 5-1

Key References

1. FHWA (2007). *Manual on Uniform Traffic Control Devices for Streets and Highways*. Washington, DC.
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SIGN DESIGN TO IMPROVE LEGIBILITY

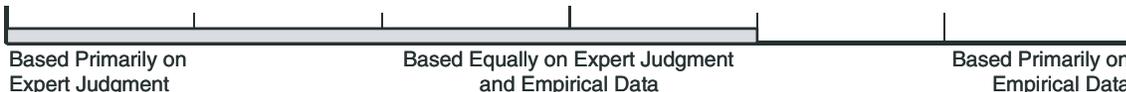
Introduction

Sign design refers to the design parameters of signs that impact the legibility of text placed on the sign. Sign legibility is greatly affected by specific design characteristics of signs that contribute to drivers' ability to perceive and understand a sign's message in order to promote safe driving behaviors. Key design parameters determining the legibility of signs include retroreflectivity (sheeting type) and legend color, font size, and font style.

Design Guidelines

The following guidelines can be used to improve sign legibility.

Sign Design Characteristics	Guidelines
Retroreflective (Sheeting Type)	<ul style="list-style-type: none"> • Microprismatic retroreflective sheeting provides longer legibility distances than encapsulated retroreflective sheeting by 9.5% (1).
Legend Color	<ul style="list-style-type: none"> • Light letters on a dark background are superior to dark letters on a light background (2). • Black-on-orange and white-on-green signs are detected at greater distances than black-on-white signs (3).
Font Size	<ul style="list-style-type: none"> • A maximum legibility index of 40 ft/in. of letter height should be used (4). • Research indicates that legibility distance increases as letter height increases, although the benefits are not proportional above letter heights of about 8 in. (3).
Font Style	<ul style="list-style-type: none"> • Legibility of overhead guide signs and shoulder-mounted guide signs is increased with microprismatic sheeting with Clearview™ alphabet over Series E (modified) (5). • Increased legibility distance is found with mixed-case text under daytime and nighttime conditions (3).
Symbol Contrast	<ul style="list-style-type: none"> • Optimal legend to background contrast value for sign legibility is 12:1 (3). • Positive-contrast signs provide greater legibility distances than negative-contrast signs (3).
General Improvements for Older Drivers (all from FHWA (6))	<ul style="list-style-type: none"> • Minimize symbol complexity by using very few details. • Maximize the distance between symbol sign elements. • Use representational rather than abstract symbols (see also Campbell, Richman, Carney, & Lee (7)). • Use solid rather than outline figures for design. • Standardize the design of arrowheads, human figures, and vehicles. • Retain maximum contrast between the symbol and the sign background. • Use a larger font when possible.



Discussion

The table on the previous page summarizes key design guidelines that can help improve sign legibility and safety. A great number of studies have examined specific properties of roadway signs that affect legibility, and many of the results from these studies are reflected in the MUTCD. Garvey, Thompson-Kuhn, and Pietrucha (3) contributed a number of the guidelines on the previous page; this data source was a comprehensive review and synthesis of existing research associated with the use and design of roadway signs.

Design Issues

Drivers cannot see as well under nighttime conditions as they can under normal daytime conditions. Additional factors that compromise vision at night, consequently affecting legibility distances, are summarized in the following table.

Factors that Compromise Vision at Night	
Glare	Glare from headlights, overhead signs, and construction lights can cause problems for approaching drivers. Drivers traveling in the same direction may experience glare issues when lights shine in their rearview mirrors.
Fatigue/Lack of Alertness	Fatigue and lack of alertness problems increase at night. The degree of these problems may be more apparent as drive time increases.
Poor Lighting	When driving during the daytime there is usually enough light to see well. This is not true at night. Even with the presence of lights, the road scene may still be confusing as signs may be hard to see amongst other signs, shop windows, and other lights.
Headlights	Headlights provide the main source of light for drivers to see and be seen under nighttime conditions. Drivers cannot see as far or see as much detail with headlights as compared to daytime driving conditions. Also, drivers tend to overdrive their headlights under certain conditions at night. Typically, the maximum distance for which modern headlamps provide reasonable illumination is between 150 and 250 ft, depending on headlamp characteristics and the reflectivity of the object being seen (8). In urban/suburban areas, drivers normally dim their headlights, which reduces visibility distance. Prismatic grade sign sheeting helps improve driver visibility in these areas.
Windshield and Mirrors	Bright lights at night can cause dirt on windshields or mirrors to create glare.

Cross References

Driver Comprehension of Signs, 18-8

Key References

1. Carlson, P.J., and Hawkins, G. (2003). Legibility of overhead guide signs with encapsulated versus microprismatic retroreflective sheeting. *Transportation Research Record*, 1844, 59-66.
2. Sivak, M., and Olson, P.L. (1983). *Optimal and Replacement Luminances of Traffic Signs: A Review of Applied Legibility Research*. (UMTRI-83-43). Ann Arbor: University of Michigan Transportation Research Institute.
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4. Chrysler, S.T., Carlson, P.J., and Hawkins, H.G. (2002). *Nighttime Legibility of Ground-Mounted Traffic Signs as a Function of Font, Color, and Retroreflective Sheeting Type*. (FHWA/TX-03/1796-2, TTI: 0-1796). College Station: Texas Transportation Institute.
5. Hawkins, H.G., Jr., Picha, D.L., Wooldridge, M.D., Greene, F.K., and Brinkmeyer, G. (1999). Performance comparison of three freeway guide sign alphabets. *Transportation Research Record*, 1692, 9-16.
6. FHWA (1995). *Improvements in Symbol Sign Design to Aid Older Drivers. Summary Report*. (FHWA-RD-95-129). McLean, VA.
7. Campbell, J.L., Richman, J.B., Carney, C., and Lee, J.D. (2004). *In-Vehicle Display Icons and Other Information Elements. Volume I: Guidelines* (FHWA-RD-03-065). McLean, VA: FHWA. (<http://www.tfhrc.gov/safety/pubs/03065/index.htm>).
8. Schiller, C., Holger, S., Groh, A., Böll, M., and Khanh, T.Q. (2009). *HID vs. Tungsten Halogen Headlamps: Driver Preferences and Visibility Distance*. (2009-01-0550). Warrendale, PA: Society of Automotive Engineering.

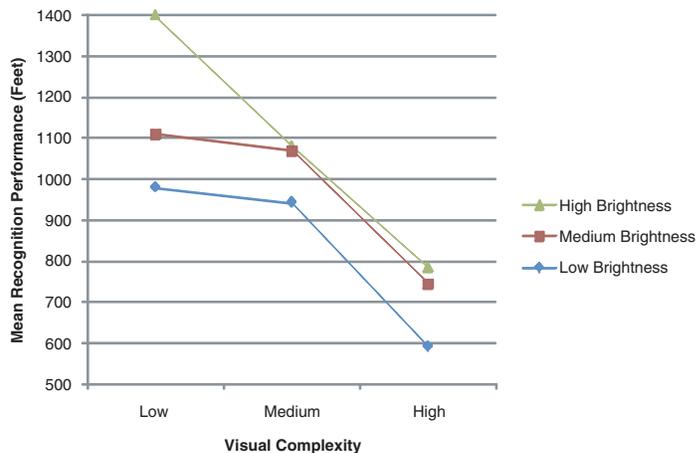
CONSPICUITY OF DIAMOND WARNING SIGNS UNDER NIGHTTIME CONDITIONS

Introduction

Conspicuity refers to how easy it is to see and locate a visual target. In the context of road signs, it represents how easy it is to distinguish a sign from the surrounding visual environment. Visual conspicuity is particularly important when providing important information because drivers are typically reluctant to spend more than 2 s with their eyes off of the roadway. Consequently, the easier drivers can find a sign, the more time they have to comprehend the sign information. Also, at a more basic level, increasing the conspicuity of a sign will reduce the chance that drivers will miss or be unable to read the sign information altogether. Nighttime visibility is a special problem for sign design, as reduced illuminance (relative to daytime conditions) is associated with reduced target contrast and generally reduced visibility for drivers. Related to warning signs in general, the MUTCD (1) provides design considerations that specify that “devices should be designed so that features such as size, shape, color, composition, lighting or retroreflection, and contrast are combined to draw attention to the devices.” As discussed in more detail below, a critical factor in facilitating the driver’s ability to find and comprehend warning signs at night is to maximize the sign’s visual conspicuity relative to surrounding background elements. The figure below illustrates the relationship between sign recognition by drivers, sign brightness, and the complexity of the sign’s immediate environment.

Design Guidelines	
Sign Characteristics	Environment Characteristics
<ul style="list-style-type: none"> • Increase sign brightness relative to its surround. • Increase brightness contrast between different parts/elements of the sign. • Increase the sign’s size relative to other objects in the visual field/environment. • Use a sign hue that contrasts with other noise/background items. 	<ul style="list-style-type: none"> • Reduce the number and density of background noise items, especially those immediately adjacent to the sign. • Increase the distance between the sign and noise items.

RECOGNITION PERFORMANCE BY VISUAL COMPLEXITY AND SIGN BRIGHTNESS



Source: adapted from Mace, King, and Dauber (2)

Discussion

Mace et al. (2) describe a study conducted to establish luminance levels for conspicuity of yellow diamond warning signs at night. A key finding of the study was that, while many factors influence the visibility of a road sign, the visual complexity of a scene is most important in determining nighttime sign luminance requirements. Specifically, the complexity of the area immediately surrounding a sign (e.g., other signs, lights, structures, trees, etc.) greatly influences a driver's ability to perceive and extract information from a sign.

When sites are assessed or classified on their visual complexity, the following factors are rated:

- The amount of detail visible in the visual scene, quantified as the number of objects or percentage of the scene with visible detail
- The number of bright light sources—streetlights, signs, cars, billboards, store windows, reflection, etc.—located in the scene
- The amount of visible detail contained in the *cone* (that portion on the right-hand side of the roadway where a driver would typically look for road signs) of the scene
- The visual demands associated with the portion of the roadway associated with the sign (i.e., the percentage of the driver's time that would be spent looking for driving-relevant information while at that location)

A broader summary of relevant research provided in Mace et al. (2) concluded that the attention-getting value of a target increases as (1) the target's brightness increases, (2) the brightness contrast between the target and its surround increases, (3) the brightness contrast between different parts of the target increases, (4) the target's size increases relative to other stimuli in the visual field, (5) the shape of the target contrasts with noise items, (6) the target's hue contrasts with noise, (7) the number of noise elements in the visual field decreases, (8) the overall density of noise items in the visual field decreases, (9) the density of noise items immediately adjacent to the target decreases, (10) the distance between the target and noise increases, (11) the number of irrelevant classes of stimuli in the visual field decreases, and (12) the variability within each irrelevant class of stimuli decreases. Although sign conspicuity is clearly important, compliance with the specifications set by the MUTCD for sign shape and other characteristics is essential.

Design Issues

A key factor to consider in improving the conspicuity and visibility of highway signs is the importance of individual differences across the driver population. In particular, older drivers have poorer rates of detection and recall of signs than do younger drivers (3), and slower response times (4). Thus, conspicuity and visibility for older drivers should be a key concern in the design and placement of signs.

Another factor in driver reaction to signs is their relevance to the drivers at a particular time and place. A series of studies have demonstrated that the greater the relevance to a particular trip and the greater their need for the information provided by the sign, the more likely that drivers will pay attention to the sign (5).

Cross References

Presentation to Maximize Visibility and Legibility, 19-4

Key References

1. FHWA (2007). *Manual on Uniform Traffic Control Devices for Streets and Highways*. Washington, DC.
2. Mace, D.J., King, R.B., and Dauber, G.W. (1985). *Sign Luminance Requirements for Various Background Complexities* (FHWA-RD-85-056). McLean, VA: FHWA.
3. Al-Gadhi, S.A., Naqvi, S.A., and Abdul-Jabbar, A.S. (1994). Driver factors affecting traffic sign detection and recall. *Transportation Research Record, 1464*, 36-41.
4. Garvey, P.M., and Kuhn, B.T. (2004). Highway sign visibility. In *Handbook of Transportation Engineering*. (Chapter 11). New York: McGraw-Hill.
5. MacDonald, W.A., and Hoffmann, E.R. (1984). *Drivers' Awareness of Traffic Sign Information*. (AIR 382-1). Vermont South, Victoria: Australian Road Research Board.

DRIVER COMPREHENSION OF SIGNS

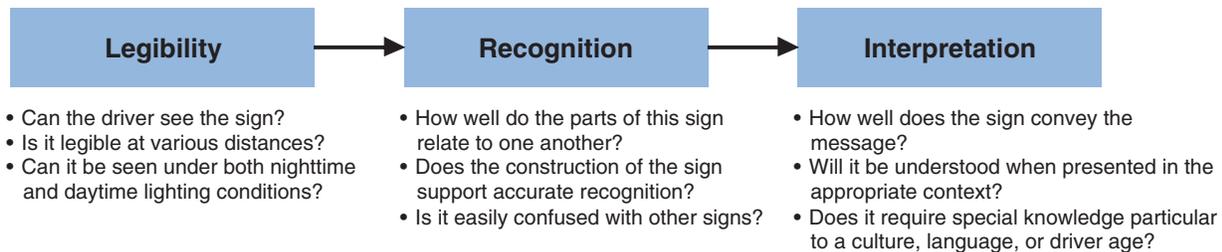
Introduction

Sign comprehension refers to a driver’s or road user’s ability to interpret the meaning of a sign. Signs should be designed and presented so that their message is comprehended and understood by users. As discussed in Campbell, Richman, Carney, and Lee (1), in the context of icons and symbols, there are three stages associated with the comprehension and use of signs: legibility, recognition, and interpretation. Legibility reflects the relationships among the driver, the sign, and the environment; it is essential for the initial perception of the sign and includes parameters such as luminance uniformity, contrast, and size. Recognition reflects whether or not the driver can readily distinguish the sign, especially in the context of other signs and stimuli. Interpretation reflects the relationships among the driver, the sign, and the referent or message associated with the sign; it includes parameters such as whether the driver comprehends the meaning, intent, or purpose of the sign. This guideline identifies message format recommendations for improving drivers’ comprehension of road signs. As shown below, information can be presented in a text-only, graphic/icon-only, or mixed text–graphic format.

Design Guidelines					
The following guidelines provide parameters for the use of text-only, graphic/icon-only, or mixed text–graphic formats.					
Format	Example	Guidelines			
Text Only		<ul style="list-style-type: none"> Use for highly complex messages. Use when indicating hazards. Use for destination information. Use in areas requiring unexpected or unique driver actions, e.g., frequent lane shifts. 			
Graphic / Icon Only		<ul style="list-style-type: none"> Use for safety and warning information. Use for prohibited actions. Use in visually degraded conditions. Use in areas with higher posted speeds. Use diagrammatic graphics when road geometry violates driver expectancies. Minimize symbol complexity by using few details. 			
Mixed		<ul style="list-style-type: none"> Add text when symbols alone are unintuitive. Keep text to no more than two to three words. Use a clear and simple font for the text. 			
<table style="width: 100%; border: none;"> <tr> <td style="width: 33%; border: none; text-align: center;"> <div style="border: 1px solid black; height: 15px; width: 100%;"></div> Based Primarily on Expert Judgment </td> <td style="width: 34%; border: none; text-align: center;"> <div style="border: 1px solid black; height: 15px; width: 100%;"></div> Based Equally on Expert Judgment and Empirical Data </td> <td style="width: 33%; border: none; text-align: center;"> <div style="border: 1px solid black; height: 15px; width: 100%;"></div> Based Primarily on Empirical Data </td> </tr> </table>			<div style="border: 1px solid black; height: 15px; width: 100%;"></div> Based Primarily on Expert Judgment	<div style="border: 1px solid black; height: 15px; width: 100%;"></div> Based Equally on Expert Judgment and Empirical Data	<div style="border: 1px solid black; height: 15px; width: 100%;"></div> Based Primarily on Empirical Data
<div style="border: 1px solid black; height: 15px; width: 100%;"></div> Based Primarily on Expert Judgment	<div style="border: 1px solid black; height: 15px; width: 100%;"></div> Based Equally on Expert Judgment and Empirical Data	<div style="border: 1px solid black; height: 15px; width: 100%;"></div> Based Primarily on Empirical Data			

Discussion

The figure below shows the three stages that appear to be associated with comprehension and use of signs: legibility, recognition, and interpretation. As shown below, this sequence of icon comprehension refers to the perceptual and cognitive process by which users interpret the meaning of a sign.



Source: adapted from Campbell et al. (1)

The format of a sign—i.e., text only, graphic/icon only, or mixed—should be selected to maximize information transmission and comprehension, given the nature of both the sign’s message and the general roadway environment. Text-based signs are clearly more appropriate for highly complex messages, such as destination messages or hazard warnings that are more quickly and easily presented via text. It has long been recognized that well-designed icons are generally recognized more accurately and quickly than text-based signs meant to convey the same message (2) and that icons can be presented in a much more spatially condensed form (3, 4, 5) than can most text-based messages. Road signs also have a limited amount of space for presenting information and must take advantage of the ability of icons to present more information to the driver than can be presented textually. Research in this domain has shown that icons can be recognized more rapidly and are legible at greater distances than information presented in other formats (6, 7). The absolute numerical differences in mean reaction times are not relevant because of the differences between the task performed in the study and the actual driving task.

Design Issues

Comprehension tests are evaluation techniques that provide a means to determine whether a candidate sign for a roadway message is likely to be properly understood by typical roadway users. Overall, a rigorous and iterative evaluation process will increase the likelihood that the implementation of the sign on the roadway will improve overall traffic safety, and not detract from it. A number of procedures can be used to measure driver comprehension of signs, including the recently released J2830, *Process for Comprehension Testing of In-Vehicle Icons*, an SAE Information Report within the SAE Standards series.

Also, road engineers may consider message format based on location and driver demographics. For example, non-native-English speakers can correctly interpret graphic messages without relying on their knowledge of the English language. An increased use of transportation graphic signs in the vicinity of non-native-English-speaking population areas may be appropriate.

Cross References

Presentation to Maximize Visibility and Legibility, 19-4

Key References

1. Campbell, J.L., Richman, J.B., Carney, C., and Lee, J.D. (2004). *In-Vehicle Display Icons and Other Information Elements. Volume I: Guidelines* (FHWA-RD-03-065). McLean, VA: FHWA (<http://www.tfhrc.gov/safety/pubs/03065/index.htm>).
2. Edworthy, J., and Adams, A. (1996). *Warning Design: A Research Prospective*. Bristol, PA: Taylor & Francis.
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COMPLEXITY OF SIGN INFORMATION

Introduction

The *complexity of sign information* refers to the number of information units presented as part of a roadway sign message. In this context, an information unit can describe geography (e.g., city), type of roadway (e.g., highway), event causes (e.g., stalled vehicle), event consequences (e.g., traffic jam), time and distances, and proposed actions. Therefore, information units can be described as the relevant words in a message. Much of the guideline information presented below has been adapted from Campbell, Carney, and Kantowitz (1).

Design Guidelines		
<ul style="list-style-type: none"> Messages that require an urgent action should be a single word or a short sentence with the fewest number of syllables possible. Drivers should be able to understand the message immediately. Messages that are not urgent or for which a response may be delayed can be a maximum of 7 units of information in the fewest number of words possible. If the information cannot be presented in a short sentence, the most important information should be presented at the beginning and/or the end of the message. Navigation instructions should be limited to 3 or 4 information units. 		
 <p style="font-size: small; margin: 0;">Based Primarily on Expert Judgment</p>	<p style="font-size: small; margin: 0;">Based Equally on Expert Judgment and Empirical Data</p>	<p style="font-size: small; margin: 0;">Based Primarily on Empirical Data</p>

DETERMINING THE NUMBER OF INFORMATION UNITS

4 units	<u>Road Construction Ahead</u> at <u>Jaspertown</u>
8 units	<u>Road Construction on Interstate 5</u> for next <u>10 miles</u> Take <u>Highway 99</u>
11 units	<u>Interstate 80 closed for construction</u> between <u>Iowa City</u> and <u>Cedar Rapids</u> <u>Exit at West Liberty</u> and drive <u>north</u> on <u>Highway 16</u>
16 units	<u>Accident Ahead</u> <u>Exit 215</u> closed to <u>Dover</u> Traffic <u>detoured</u> to <u>Exit 216</u> Follow <u>Highway 46</u> to <u>Chester</u> and <u>turn east</u> onto <u>Inglenook Road</u>

EFFECTS OF INFORMATION COMPLEXITY

	Length of Message			
	3-4 units	6-8 units	10-12 units	14-18 units
Duration of Each Glance	1.08 s	1.18 s	1.20 s	1.35 s
Number of Glances	3.8	6.9	9.6	15.5
Memory Recall	100%	97.5%	75.4%	52.4%

Source: Labiale (2)

Discussion

The longer the message, the more processing time the driver requires. Therefore, messages that require the driver to make an immediate response should be as short as possible. One-word messages informing the driver of the appropriate action to take might work best in these situations. As the response required by the driver becomes less and less urgent, the messages can become more detailed; however, an effort should still be made to make the messages as concise as possible.

Zwahlen, Adams, and DeBald (3) analyzed the number of lane deviations that occurred while drivers were operating a CRT touch screen. The results suggest that the number of glances away from the roadway should be limited to three and that glance durations that exceeded 2 s in duration are unacceptable. Zwahlen et al. (3) examined the amount/complexity of information necessary for evoking these unsafe glance frequencies and durations. The results of this on-road study suggest that although the duration of glances does not increase dramatically as the number of information units increase, the number of glances does. Therefore, the shortest information message (3 to 4 units) would be the most appropriate for keeping drivers' attention on the forward roadway. The driver's ability to recall information was also examined in Labiale (2): only 75% of a 10- to 12-unit message could be recalled, in comparison to 100% of a 3- to 4-unit message and 98% of a 6- to 8-unit message. This finding is consistent with Miller (4), which proposed that the maximum capacity of working memory is "seven, plus or minus two" chunks of information. Again, this finding suggests that keeping the message short, 3 to 8 information units, would increase the likelihood that it will be recalled by the driver.

Design Issues

Complexity is a function of how much information is being provided and how difficult it is to process. The phrase "information units" is used to describe the amount of information presented, in terms of key nouns and adjectives contained within a message.

High-Complexity Examples	Low-Complexity Examples
> 9 information units	3-5 information units
Processing time > 5 s	Processing time < 5 s
Examples: Topographical representations of a route, or full route maps, or schedules for alternative modes of transportation.	Examples: Directions of turns, or estimates of travel costs.

Cross References

Driver Comprehension of Signs, 18-8

Key References

1. Campbell, J.L., Carney, C., and Kantowitz, B.H. (1998). *Human Factors Design Guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO)* (FHWA-RD-98-057). Washington, DC: FHWA.
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Changeable Message Signs

When to Use Changeable Message Signs	19-2
Presentation to Maximize Visibility and Legibility	19-4
Determining Appropriate Message Length	19-6
Composing a Message to Maximize Comprehension	19-8
Displaying Messages with Dynamic Characteristics	19-10
Changeable Message Signs for Speed Reduction	19-12
Presentation of Bilingual Information	19-14

WHEN TO USE CHANGEABLE MESSAGE SIGNS

Introduction

When to use changeable message signs refers to the general principles regarding the appropriate display of traveler information messages on CMSs. These signs can be used to effectively manage travel, control traffic, identify current and anticipated roadway conditions, and regulate access (1). However, inappropriate application and use can reduce the effectiveness of these signs. Note that the terms “changeable message sign” (CMS), “dynamic message sign” (DMS), and “variable message sign” (VMS) are used interchangeably in the literature to refer to these signs. Because there is no functional distinction between the terms, “changeable message sign” or “CMS” is used throughout this chapter to refer to CMSs, DMSs, and VMSs.

Design Guidelines	
<p>The following guidelines can be used to improve the effectiveness of displaying traveler information with CMSs.</p>	
When to Use CMSs	Examples (adapted from Dudek (4))
<ul style="list-style-type: none"> • To display essential information about: <ul style="list-style-type: none"> – Random unpredictable incidents such as crashes – Temporary, pre-planned activities such as construction – Environmental problems such as snow – Special event traffic such as for parades – Special operational problems such as reversible lanes – Recurrent problems such as travel times due to congestion – AMBER alerts or emergency security incidents 	
<ul style="list-style-type: none"> • To display messages for less than 2 weeks. 	
<ul style="list-style-type: none"> • In conjunction with other media (e.g., Highway Advisory Radio) if conveying extensive or complex messages. 	
<ul style="list-style-type: none"> • To display up-to-date, real-time information that is accurate and credible. 	
	
<p>Based Primarily on Expert Judgment Based Equally on Expert Judgment and Empirical Data Based Primarily on Empirical Data</p>	

Discussion

CMSs are an essential part of the driver information system. They are an important link between transportation agencies and the driving public. They allow for the display of time-sensitive or temporary information that affects travel and in many cases requires drivers to take an action (1). It is important that drivers find these messages to be relevant so that they will continue to pay attention to the signs. A field study analyzed by Richards and Dudek (2) showed that CMSs that are operated for long periods with the same message may lose their effectiveness. If drivers begin ignoring a sign, they may not notice or may ignore important roadway information when it is available (3). Johnson (1) also states that drivers tend to ignore messages that are displayed for long periods of time and recommends that safety campaign messages be limited to a few weeks.

The content displayed on CMSs is limited by the amount of time that the driver has to read the display. This time is affected by both the legibility distance of the sign and the speed of travel. The legibility distance is influenced by a number of factors including weather conditions (e.g., rain, fog), geography (e.g., hills), and roadway conditions (e.g., the presence of large trucks) (4). CMS reading times are higher than those for static signs because drivers can scan static signs for essential information whereas they must read the entire CMS to understand its message. Static signs also have the advantages of being seen daily and of being uniformly formatted. At highway speeds, the CMS message must be readable in 8 s or less (4). Displaying messages that are longer than this limit can affect traffic flow and sign credibility. Thus, it is recommended that extensive messages be displayed in conjunction with other traveler information media (1). These media can include Highway Advisory Radio (HAR), 511, websites, and commercial radio. Dudek (4) provides additional guidance on message length, the number of information units in a message, and message phrasing.

Credibility is an important factor in the use of CMSs. Many factors can cause reduced message credibility including inaccurate, outdated, irrelevant, obvious, repetitive, trivial, or poorly designed messages (4). The accuracy and relevance of information such as travel time are important, because they can be easily checked by drivers. If the information is proven incorrect, sign credibility will suffer. Reduced credibility can cause drivers to distrust the system and ignore the sign.

Design Issues

There are two schools of thought concerning what to display on a CMS when no unusual conditions exist or when there are no essential messages to present: (1) always display a message on the CMS regardless of whether there is an incident or unusual condition and (2) display messages only when an incident or other situation warrants a message and blank the CMS at all other times. The advantage of displaying a message on the CMS regardless of whether there is an incident is that drivers will know that the CMS is functioning. However, only 10% to 15% of English and French drivers assume the CMS is broken when it is not displaying a message (5). (This result could be caused by the policy in these drivers' jurisdictions of blanking the screen when there are no unusual conditions.) The disadvantage is that drivers may come to ignore the sign entirely if safety campaign or other non-traffic-related messages are displayed when no unusual conditions exist (1).

Thus, this guideline recommends displaying a message only when an incident warrants it and a blank CMS at other times. This policy is followed by 77% of transportation agencies surveyed in a 1997 national survey of 26 agencies (1). It also follows the human factors principles of CMS operation: don't tell drivers something they already know and use CMS only when a driver response is required (4).

Cross References

Determining Appropriate Message Length, 19-6

Composing a Message to Maximize Comprehension, 19-8

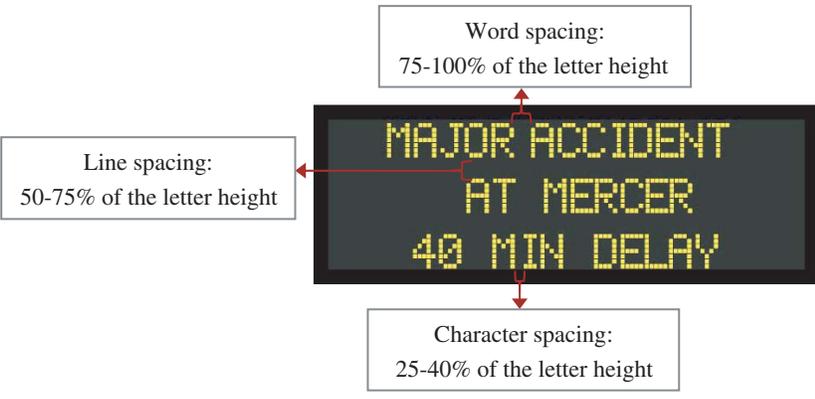
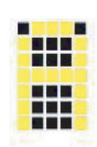
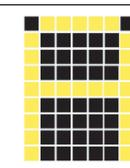
Key References

1. Johnson, C.M. (2001). *Use of Changeable Message Sign (CMS)*. FHWA Policy Memorandum response to James A. Cheatham. Retrieved June 19, 2008 from <http://www.fhwa.dot.gov/legregs/directives/policy/pame.htm>.
2. Richards, S.H., and Dudek, C.L. (1986). Implementation of work zone speed control measures. *Transportation Research Record*, 1086, 36-42.
3. Halloin, D.M. (1996). Impediments to the effective use of portable variable message signs at freeway work zones. In C. Dudek (Ed.), *Compendium of Graduate Student Papers on Advanced Surface Transportation Systems* (pp. C1-C34). College Station: Texas A&M University.
4. Dudek, C.L. (2004). *Changeable Message Sign Operation and Messaging Handbook*. (FHWA-OP-03-070). College Station: Texas Transportation Institute.
5. Montoro, L., Lucas, A., and Blanch, M.T. (2004). Specific design parameters: VMS Part I. In *The Human Factors of Transport Signs* (pp. 185-198). CRC Press.

PRESENTATION TO MAXIMIZE VISIBILITY AND LEGIBILITY

Introduction

Presentation to maximize visibility and legibility refers to how the photometric and physical characteristics of a CMS can be employed to positively affect readability. Because CMS characters or symbols are typically constructed using a relatively coarse matrix of pixels, the requirements for their visibility and legibility are more demanding than for standard, fixed signs. Also, the fixed matrix introduces limitations to character size, height-to-width ratio, spacing, and other geometric characteristics available for presenting messages. The MUTCD provides specific guidance about letter height, minimum legibility distance, and other characteristics. Additional recommendations for designing messages within the limitations imposed by CMS technologies, including guidelines for contrast ratio, luminance, character spacing, and resolution are provided below.

Design Guidelines				
CMS Characteristic	Guideline Value			
Contrast Ratio (light-emitting CMS)	<p>Optimal contrast ratio range = 8-12</p> <p>where:</p> $Contrast\ ratio = \frac{Luminance_{max}}{Luminance_{min}}$ <p>Luminance_{max} = luminance emitted by the area or element of greatest intensity (text) Luminance_{min} = luminance emitted by the area or element of least intensity (background)</p>			
Luminance (light-emitting CMS in cd/m²)		Sun Overhead	Overcast/Rain	Nighttime
	Young (16-40)	850	350	30
	Old (65+)	1000	600	30
Character Spacing (matrix CMS)	<div style="text-align: center;">  <p>Word spacing: 75-100% of the letter height</p> <p>Line spacing: 50-75% of the letter height</p> <p>Character spacing: 25-40% of the letter height</p> </div>			
Character Resolution	Size should be consistent within a display			
	 5 × 7 matrix: static or non-critical text		 7 × 9 matrix: dynamic or critical text	
<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="width: 30%; text-align: center;">  <p>Based Primarily on Expert Judgment</p> </div> <div style="width: 40%; text-align: center;">  <p>Based Equally on Expert Judgment and Empirical Data</p> </div> <div style="width: 30%; text-align: center;">  <p>Based Primarily on Empirical Data</p> </div> </div>				

Discussion

Contrast ratio: The photometric and physical properties of signs directly affect the legibility of the sign elements. For example, contrast ratios are affected by photometric properties such as luminance, but can be reduced by physical properties such as dirty or scratched protective plexiglass sheeting (1). The guidance on acceptable ranges depends on the conditions present in the ambient environment and whether the CMS is light reflecting or light emitting. Light-emitting CMSs have minimum contrast ratios on sunny days when the sun increases the background sign luminance, whereas light-reflecting CMSs have minimum contrast ratios when the light falling on the sign is at a minimum (2). Weather conditions such as rain and fog can affect contrast ratios for both types of signs by reducing the illumination coming from the sign or light reflected by the sign. The optimal contrast ratio range is between 8 and 12, although Dudek (1) presents other acceptable ranges based upon European research.

Luminance: Driver age and sun position affect the required CMS luminance significantly (3). Generally, greater luminances are required for older drivers than for younger drivers at a given distance. Garvey and Mace (3) found that during extreme backlit (sun behind the sign) and washout (sun directly on the sign) conditions, 1000 cd/m² is a minimum value. However, at 650 feet, some drivers cannot be accommodated under these visibility conditions, at any luminance level. If luminance values are too high at night, the characters may appear to *irradiate* or bleed onto the background and blur due to the extreme contrast (4).

Character spacing: Character spacing is limited by physical properties of the sign such as the matrix pattern of the LEDs. The spacing used should allow drivers to recognize (1) words as items rather than series of individual letters and (2) lines as separate entities. The included guidance is based upon the MUTCD, though Dudek (4) presents different values based upon the United Kingdom's draft CMS standards.

Character resolution: Character resolution can affect the readability of text. Campbell, Carney, and Kantowitz (5) reported that for characters smaller than approximately 22 arcminutes, a 7 × 9 matrix led to faster reading times and fewer reading errors than a 5 × 7 matrix. A 7 × 9 matrix should be used to display dynamic or critical text, while a 5 × 7 matrix can display static or non-critical text. There are obvious trade-offs between the resolution used and the amount of text that can be fit on the sign.

Design Issues

Appropriate resolution is also affected by the case of the characters presented. All uppercase letters are often displayed on CMSs and are more difficult for people to read than mixed or lowercase letters (6). People are more accustomed to reading mixed or lowercase letters and can identify word shapes using the ascenders and descenders. However, lowercase letters require a higher resolution matrix (5 × 9) to accommodate these descenders (7). The readability of lowercase letters also depends on the display of curved lines, which is a challenge on matrix displays. Thus, there are trade-offs between readability and practicality for displaying letters in mixed cases.

There are many types of CMSs available that utilize different technologies. Upchurch, Armstrong, Baaj, and Thomas (8) evaluated shuttered fiber-optic, LED, and flip disk signs to analyze the legibility distance of each. For backlit (sun directly behind sign) and nighttime conditions, LED and fiber-optic signs had better legibility distances than flip disk signs. For washout (direct sunlight on sign) and midday conditions, fiber-optic signs performed best for legibility distance. LED signs may interact negatively with sunglass filters. Sunglass lenses that have a notch filter, which attenuates light emissions in the same range that amber LEDs emit light (9), reduce the brightness of the LED, thereby decreasing the contrast and making CMS messages difficult to read.

Cross References

Key Components of Sight Distance, 5-2
 Sign Design to Improve Legibility, 18-4
 Composing a Message to Maximize Comprehension, 19-8

Key References

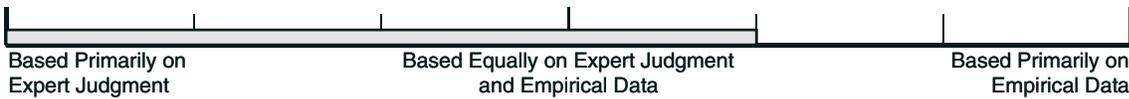
1. Dudek, C.L. (1997). *NCHRP Synthesis of Highway Practice 237: Changeable Message Signs*. Washington, DC: Transportation Research Board.
2. Dudek, C.L. (2004). *Changeable Message Sign Operation and Messaging Handbook*. (FHWA-OP-03-070). College Station: Texas Transportation Institute.
3. Garvey, P.M. and Mace, D.J. (1996). *Changeable Message Sign Visibility*. (FHWA-RD-94-077). Washington, DC: FHWA.
4. Dudek, C.L. (1992). *Guidelines on the Use and Operation of Changeable Message Signs*. (FHWA-TX-92-1232-9). College Station: Texas Transportation Institute.
5. Campbell, J.L., Carney, C., and Kantowitz, B.H. (1998). *Human Factors Design Guidelines for Advanced Traveler Information Systems (ATIS) And Commercial Vehicle Operations (CVO)*. (FHWA-RD-98-057). Washington, DC: FHWA.
6. Proffitt, D.R., and Wade, M.M. (1998). *Creating Effective Variable Message Signs: Human Factors Issues*. (VTRC 98-CR31). Charlottesville: Virginia Transportation Research Council.
7. Hitchins, D. (2001). Lowercase font set development for variable message signs (VMS). *Proceedings of the 8th World Congress on Intelligent Transport Systems* [CD-ROM].
8. Upchurch, J., Armstrong, J.D., Baaj, M.H., and Thomas, G.B. (1992). Evaluation of variable message signs: target value, legibility, and viewing comfort. *Transportation Research Record*, 1376, 35-44.
9. Halloin, D.M. (1996). Impediments to the effective use of portable variable message signs at freeway work zones. In C. Dudek (Ed.). *Compendium of Graduate Student Papers on Advanced Surface Transportation Systems* (pp. Ci-C34). College Station: Texas A&M University.

DETERMINING APPROPRIATE MESSAGE LENGTH

Introduction

Determining the appropriate message length for a CMS refers to choosing a message length that drivers have the time to comprehend as they pass the sign. Controlling message length is extremely important because there is a limited amount of time to present information to drivers. Message length is described not only by the absolute length in the number of words, but also by the number of information units included in these words. Information units are a measure of the message load, or total amount of information in the message. If there are too many words or information units in a message, it may need to be split into two phases. Dudek (1) provides additional guidance for reducing message length and splitting long messages.

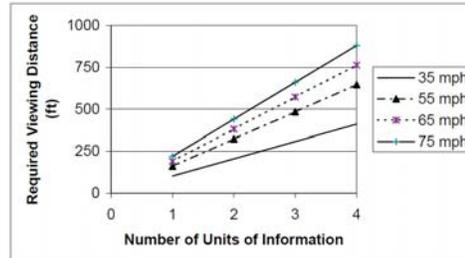
Design Guidelines												
Message Property	Guidelines	Example (from Dudek (1))										
<p>Information Units: A measure of the amount of information presented in terms of facts used to make a decision; a single information unit consists of 1 to 4 words</p>	<p>Use no more than:</p> <ul style="list-style-type: none"> 2 information units per line 3 information units per phase (see below) 4 information units per message read at speeds of 35 mi/h or more 5 information units per message read at speeds less than 35 mi/h 	<table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <thead> <tr> <th style="width: 50%;">Question</th> <th style="width: 50%;">Answer (1 information unit)</th> </tr> </thead> <tbody> <tr> <td>What is the problem?</td> <td>MAJOR ACCIDENT</td> </tr> <tr> <td>Where is the problem?</td> <td>AT US-23</td> </tr> <tr> <td>Who is the message for?</td> <td>NEW YORK</td> </tr> <tr> <td>What should they do?</td> <td>USE I-280 EAST</td> </tr> </tbody> </table>	Question	Answer (1 information unit)	What is the problem?	MAJOR ACCIDENT	Where is the problem?	AT US-23	Who is the message for?	NEW YORK	What should they do?	USE I-280 EAST
Question	Answer (1 information unit)											
What is the problem?	MAJOR ACCIDENT											
Where is the problem?	AT US-23											
Who is the message for?	NEW YORK											
What should they do?	USE I-280 EAST											
<p>Length: Number of words or characters in a message, excluding prepositions</p>	<p>Use no more than:</p> <ul style="list-style-type: none"> Eight words per message for drivers at high speeds (based on the required reading time of 1 s per four- to eight-character word, excluding prepositions, or 2 s per information unit, whichever is longest) 	<div style="text-align: center; margin-bottom: 10px;">  </div> <p>Acceptable message length because the preposition “to” does not count.</p>										
<p>Phases: Similar to a page of a book, a phase is the text that is displayed at a single point in time</p>	<ul style="list-style-type: none"> Two phases maximum per message Each phase must be able to be understood alone One line should not contain parts of 2 information units but may contain 2 whole information units When dividing messages between two phases, compatible information units should be kept on the same phase 	<p>Poorly designed message:</p> <div style="display: flex; justify-content: space-around; align-items: center; margin-bottom: 10px;"> <div style="border: 1px solid black; background-color: black; color: yellow; padding: 5px; text-align: center;"> MAJOR ACCIDENT AT US - 23 NEW YORK </div> <div style="border: 1px solid black; background-color: black; color: yellow; padding: 5px; text-align: center;"> USE I - 280 EAST </div> </div> <p>Improved message:</p> <div style="display: flex; justify-content: space-around; align-items: center;"> <div style="border: 1px solid black; background-color: black; color: yellow; padding: 5px; text-align: center;"> MAJOR ACCIDENT AT US - 23 </div> <div style="border: 1px solid black; background-color: black; color: yellow; padding: 5px; text-align: center;"> NEW YORK USE I - 280 EAST </div> </div>										



Discussion

Information units: The recommendations for the number of information units that are appropriate for display are based on research and operational experience (1). Dudek (2) summarizes that 1 s is needed per four- to eight-character word excluding prepositions or 2 s per information unit, whichever is **longer**. Using this assumption, the required viewing distance for different numbers of information units, for drivers traveling at different speeds, are included below.

REQUIRED VIEWING DISTANCE PER NUMBER OF INFORMATION UNITS AT VARYING SPEEDS (FROM DUDEK (1))



However, the MUTCD (3) states that the minimum phase display time should be based upon 1 s per word or 2 s per information unit, whichever is **shorter**. This direct contradiction of Dudek (2) causes practical consequences for drivers. If the longer time is used (2) and the message includes many short words that do not all need to be remembered, the phase display time could be unnecessarily inflated. If the shorter time is used (3) and the message includes information units composed of multiple important words, drivers may not have time to read all of them. If longer messages need to be provided, they should be shown in conjunction with other information media (See *When to Use Changeable Message Signs*, 19-2).

Length: Dudek (1) states that the appropriate absolute message length is affected by (1) the amount of time that the driver is in the legibility zone of the CMS, considering travelling speed and environmental conditions; (2) the driver workload including all driver activities such as reading signs, lane positioning, etc.; and (3) message familiarity because drivers take more time to read unfamiliar content or unusual messages

The eight-word maximum for high speeds is based on the *legibility distance*, or the distance at which the words on the sign become legible, as well as the speed that the driver is travelling. This recommendation assumes drivers are traveling at 55 mi/h and the legibility distance of the sign is 650 ft (which is the approximate legibility distance for a lamp matrix sign with 18-in. character heights) (2). If the message is too long for drivers to read at normal speeds, it is likely that some drivers will slow down to be able to read the message, affecting the traffic flow (1). In general, the message length should be reduced as much as possible without losing the message intent (1). The message length can be reduced by the use of alternative phrases or appropriate abbreviations and the removal of redundant and unimportant information.

Phases: Dudek (1) reports that research has shown drivers have difficulty reading messages that are on more than two phases. Because either the first phase or the second phase may be read first by a passing driver, each phase should make sense by itself. This is accomplished by keeping compatible information units in the same phase. In addition, portions of two different information units should not be displayed on a single line because it is confusing to drivers and increases reading time (1).

Design Issues

The legibility distance for a CMS is affected by a number of factors. If the sign is placed off to the side of the roadway rather than directly over the travel lanes, additional sight distance is required (1) because a driver's field of view is assumed to be between 10° right and left of head-on. Proffitt and Wade (4) support rotating the CMS 5° to 10° toward the roadway to increase the amount of time that roadside signs are at an optimal reading angle. However, conflicting ideas exist regarding the assumed angular range of the legibility distance. This distance is also affected by lighting conditions, sun position, vertical curvature, horizontal curvature, spot obstructions, rain, fog, and trucks in the traffic stream (1). If the legibility distance of the sign is reduced, then the time that the driver has to read the sign is reduced, necessitating a reduction in the number of information units contained on the sign.

Cross References

Key Components of Sight Distance, 5-2
Changeable Message Signs, 13-6
When to Use Changeable Message Signs, 19-2

Presentation to Maximize Visibility and Legibility, 19-4
Composing a Message to Maximize Comprehension, 19-8
Displaying Messages with Dynamic Characteristics, 19-10

Key References

1. Dudek, C.L. (2004). *Changeable Message Sign Operation and Messaging Handbook*. (FHWA-OP-03-070). College Station: Texas Transportation Institute.
2. Dudek, C.L. (1992). *Guidelines on the Use and Operation of Changeable Message Signs*. (FHWA-TX-92-1232-9). College Station: Texas Transportation Institute.
3. FHWA (2009). *Manual on Uniform Traffic Control Devices for Streets and Highways*. Washington, DC.
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COMPOSING A MESSAGE TO MAXIMIZE COMPREHENSION

Introduction

Composing a CMS message to maximize comprehension refers to message formatting issues that affect driver understanding or reading times. Driver comprehension is important because the message may provide a legitimate safety warning that requires the driver to take an action. Drivers have a limited amount of time to comprehend the information and make a decision. Messages that are easy to comprehend reduce the amount of time required to read and grasp the meaning of the message, facilitate decision making, and promote faster responses. The following guidelines can be used to increase driver comprehension of signs.

Design Guidelines																	
Message Property	Guidelines																
Abbreviations	<ul style="list-style-type: none"> Avoid using abbreviations whenever possible. If abbreviations are necessary, use approved abbreviations from Section 1A.14 of the MUTCD. If the MUTCD does not include the desired abbreviation, create an abbreviation by removing letters from the end of a word until it is the desired length. 																
Date/Day Format	<ul style="list-style-type: none"> If the dates are in the next week: <ul style="list-style-type: none"> – Use days of the week rather than calendar dates (e.g., “Tue – Thur”) – Do not use “For 1 Week” because the start and end dates are ambiguous – “Nite” may be used in place of “Night” – A hyphen with a space on either side may be used in place of “Thru” – “Weekend” may be used if the event begins on Saturday morning and ends on Sunday evening If the dates are not in the next week: <ul style="list-style-type: none"> – Use a three-letter month abbreviation rather than a numerical month representation (i.e., “Apr 21” rather than “4/21”) – Only state the month once if both dates in a range are in the same month (i.e., “Apr 21 – 23” rather than “Apr 21 – Apr 23”) – Don’t include day, date, <i>and</i> time information 																
Element Order	<p>Recommended precedence order for message elements is shown below. Note that only a limited number of elements should be included in a single message (adapted from Dudek (1)).</p> <table border="1" style="width: 100%; border-collapse: collapse; margin-left: 20px;"> <thead> <tr style="background-color: #D3D3D3;"> <th style="width: 30%; padding: 5px;">Message Element</th> <th style="padding: 5px;">Element Description</th> </tr> </thead> <tbody> <tr> <td style="padding: 5px;">1. Incident/Roadwork/ Closure Descriptor</td> <td style="padding: 5px;">Description of the unusual situation (use closure descriptor when all lanes on the roadway or ramp are closed)</td> </tr> <tr> <td style="padding: 5px;">2. Incident/Roadwork/ Closure Location</td> <td style="padding: 5px;">Location of the unusual situation</td> </tr> <tr> <td style="padding: 5px;">3. Lanes Closed/Blocked</td> <td style="padding: 5px;">Description of the exit ramps or lanes that are closed or blocked; can be used instead of Element 1</td> </tr> <tr> <td style="padding: 5px;">4. Effect on Travel</td> <td style="padding: 5px;">Description of the severity of the situation to help the driver decide whether or not to divert (e.g., delay or travel time)</td> </tr> <tr> <td style="padding: 5px;">5. Audience for Action</td> <td style="padding: 5px;">Used when the action applies to a subset rather than all drivers</td> </tr> <tr> <td style="padding: 5px;">6. Action</td> <td style="padding: 5px;">Tells drivers what to do</td> </tr> <tr> <td style="padding: 5px;">7. Good Reason for Following the Action</td> <td style="padding: 5px;">Gives drivers confidence that following the action will improve safety or save time</td> </tr> </tbody> </table>	Message Element	Element Description	1. Incident/Roadwork/ Closure Descriptor	Description of the unusual situation (use closure descriptor when all lanes on the roadway or ramp are closed)	2. Incident/Roadwork/ Closure Location	Location of the unusual situation	3. Lanes Closed/Blocked	Description of the exit ramps or lanes that are closed or blocked; can be used instead of Element 1	4. Effect on Travel	Description of the severity of the situation to help the driver decide whether or not to divert (e.g., delay or travel time)	5. Audience for Action	Used when the action applies to a subset rather than all drivers	6. Action	Tells drivers what to do	7. Good Reason for Following the Action	Gives drivers confidence that following the action will improve safety or save time
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Justification	<table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 30%; padding: 5px; vertical-align: top;">Use staircase indentation for rows:</td> <td style="padding: 5px; border: 1px solid black;"> <div style="text-align: center;"> 1) Justify top row at left 2) Center middle row 3) Justify bottom row at right </div> </td> </tr> </table>	Use staircase indentation for rows:	<div style="text-align: center;"> 1) Justify top row at left 2) Center middle row 3) Justify bottom row at right </div>														
Use staircase indentation for rows:	<div style="text-align: center;"> 1) Justify top row at left 2) Center middle row 3) Justify bottom row at right </div>																
Message Specificity	<ul style="list-style-type: none"> Provide specific diversion or incident location information when available. Use the phrase “This Exit” instead of the phrase “Next Exit” to refer to the upcoming exit. 																

Based Primarily on Expert Judgment	Based Equally on Expert Judgment and Empirical Data	Based Primarily on Empirical Data
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Discussion

Abbreviations: Abbreviations provide the benefit of reduced message length; however, their use is discouraged because they have been found to decrease message comprehension (2) and increase reading times (3). However, due to fixed sign size and message length recommendations, abbreviations can be necessary to convey the information to the level of specificity desired. Proffitt and Wade (3) report that in a study of sonar operators, viewers preferred truncated abbreviations over conventional (created by experts) or contraction (vowel removed) abbreviations. Truncated abbreviations proved to have faster response times and improved decoding times with subsequent trials.

Date format: Research has shown that drivers have difficulty converting calendar dates to appropriate days of the week (1). However, it is often desirable to present closure or other information more than 1 week in advance, necessitating the inclusion of numeric date information in the message. In a laptop study examining date formats, Ullman, Ullman, and Dudek (9) found that regardless of the format that was used to present the day and date information, only approximately 75% of drivers could tell if the event would impact their current or future travel.

Element order: The order of elements in a message varies widely depending on what information is known and appropriate to describe the incident. The MUTCD (4) states that on portable message signs, “if the message can be displayed in one phase, the top line should present the problem, the center line should present the location or distance ahead, and the bottom line should present the recommended driver action.” This recommendation loosely maps to the recommended order of message elements by Dudek, included on the previous page (1).

Justification: Greenhouse (2) found that staircase-justified messages increase reader comprehension, perhaps because this style better matches drivers’ eye movements as they read the message. This recommendation contradicts the MUTCD standard that all text should be center justified (4).

Message specificity: Message specificity is a message property that is affected by many different message aspects including space available on the sign, the information available to the Traffic Management Center, information unit limits, and message length limits. Wang, Collyer, and Yang (8) found through participant questionnaires that more specific messages (i.e., “Accident at Exit 12/Major Delays to Boston/Use Route I-295”) are preferred to less specific messages (i.e., “Accident at Exit 12/Major Delays/Use Other Routes”). Pedic and Ezrakhovich (5) also report that drivers are more likely to correctly interpret a message when it includes a specific diversion task instead of a generic task. Drivers are also more willing to divert if given the incident location, expected delay, and best detour strategy rather than just a subset of that information (6). Survey data show that precise location information was preferred so drivers could make informed decisions about exiting/re-entering the roadway (7). When expressing exit information, “This Exit” instead of “Next Exit” was preferred to refer to the upcoming exit (7).

Design Issues

When used in messages, signal words (e.g., “Danger,” “Warning,” “Caution”) may not be interpreted as intended and do not affect driver performance (3). Avoiding the use of such words can reduce reading time, conserve sign space, and prevent driver confusion.

Sign comprehension also depends on driver literacy. Weak readers depend more on the message context for comprehension, are more affected by text degradation (similar to bulb burn-out on CMS), and hold more parts of a message in memory at a single time due in part to slower reading (3). Thus, Proffitt and Wade (3) recommend the use of context about the message subject, standardized message formats to enhance familiarity, and distinct directional statements. Because there is no literacy test required for driver licensing, message composition should accommodate varying reading competencies.

Another aspect that affects comprehension is the use of symbols. Symbols can convey information without requiring driver literacy. In general, symbolic signs are recognized better, faster, and from further away than the corresponding text signs (3). However, care should be taken in their use because the meaning of symbolic signs is not always as well understood. Using a CMS to display television pictures of conditions or maps was not positively received by a majority of survey respondents (7).

Cross References

Driver Comprehension of Signs, 18-8

Presentation to Maximize Visibility and Legibility, 19-4

Presentation of Bilingual Information, 19-14

Key References

1. Dudek, C.L. (2004). *Changeable Message Sign Operation and Messaging Handbook*. (FHWA-OP-03-070). College Station: Texas Transportation Institute.
2. Greenhouse, D. (2007). *Optimizing Comprehension of Changeable Message Signs (CMS)*. (UCB-ITS-PRR-2007-24). Berkeley: University of California Partners for Advanced Transit and Highways (PATH).
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8. Wang, J.-H., Collyer, C.E., and Yang, C.-M. (2005). *Enhancing Motorist Understanding of Variable Message Signs*. (FHWA-RIDOT-RTD-06-1). Providence: Rhode Island Department of Transportation.
9. Ullman, G.L., Ullman, B.R., and Dudek, C.L. (2007). Evaluation of alternative dates for advance notification on portable changeable message signs in work zones. *Transportation Research Record*, 2015, 36-40.

DISPLAYING MESSAGES WITH DYNAMIC CHARACTERISTICS

Introduction

Dynamic characteristics refer to message properties that specify character movement. These characteristics include the time to display each message phase, blanking between phases of a multi-phase message, flashing one or more lines of a message, alternating lines in multi-phase messages, and *looming* (making text or symbols increase in size over time). Improper use of dynamic message characteristics can lead to increased reading times and reduced message comprehension.

Design Guidelines			
Topic	Definition	Guideline	Rationale/Source
Phase Display Time	The amount of time to display each phase of a two-phase message	Use whichever is longest: <ul style="list-style-type: none"> 2 s per information unit <i>or</i> 1 s per four- to eight-character word (excluding prepositions) 	Research and field experience (1)
Blank Time between Phases	The amount of time that a CMS is left completely blank between message phases	Insert a 300 ms blank screen between message phases 1 and 2.	Increased word and number comprehension (3)
Flashing Messages	One-phase messages that flash the entire message	Do not use.	Disagreement in research results (4, 5)
	One-phase messages that contain one flashing or blinking line	Do not use.	Increased reading time and reduced comprehension (4, 5)
Alternating-Line Messages	Multiple-phase messages in which only a subset of the lines change between phases	Do not use.	Increased reading time (4, 5)
Looming	Increasing text or symbol size over time	Do not use.	No positive effect (3)

Based Primarily on Expert Judgment

Based Equally on Expert Judgment and Empirical Data

Based Primarily on Empirical Data

BLANK TIME BETWEEN CYCLES (FROM DUDEK (1))

TYPE OF CMS	EXAMPLE	BLANK TIME BETWEEN CYCLES
One-word or one-line sign with three or more phases		0.25 s blank screen + 0.50 s screen with 3 asterisks + 0.25 s blank screen OR 0.25 s or less between phases + 1.00 s between cycles

EQUATION: HOW MUCH TIME SHOULD BE USED TO DISPLAY EACH PHASE?

1. Find the time that is available for the entire message T = total time available to read the message	$T(s) = \frac{\text{Legibility Distance (ft)}}{\text{Traveling Speed (ft/s)}}$
2. Find the time that is needed for each phase x = number of information units in phase 1 y = number of information units in phase 2	Time for phase 1 (t_1) = 2x Time for phase 2 (t_2) = 2y
3. Make sure that the time required is less than or equal to the time available B = blanking time between phases	$T \geq B + t_1 + t_2$

Discussion

Only a limited amount of research has been conducted on the dynamic properties of message signs (2). In addition, most of the studies have been conducted in laboratory or simulator settings rather than on the road.

Phase display time: The amount of time that a single phase should be displayed is determined by the amount of content in that phase. Dudek (1) summarizes that either 1 s is needed per four- to eight-character word excluding prepositions or 2 s is needed per information unit, whichever is longest. The total time available to divide between the phases is reduced by the blank time between the phases, discussed below.

Blank time between phases: Greenhouse (3) found that inserting a 300 ms blank screen between phase 1 and phase 2 of a portable message sign improves comprehensibility. This improvement is possibly because a refractory period helps information processing between screens. Although this conclusion applies directly to portable message signs, it may be true for permanent message signs as well. Note that the blank screen was only tested between phase 1 and phase 2, not between phase 2 and phase 1 when the message cycled. It is unknown if providing a blanking time between phase 2 and phase 1 would provide a further benefit. It is reasonably conceivable that drivers who see a blank between phases 1 and 2, but not between phases 2 and 1, would reverse the order of the phases and possibly have trouble understanding the message. Dudek (1) recommends that blank time and/or asterisks be displayed between cycles of a message that contains three or more phases (on one-word or one-line signs). Because these signs are more limited in the amount of information that they can display at one time, the phases may not make sense independently and drivers who read later phases before phase 1 may not understand the message. Thus, giving an indication of where the message is in the cycle gives drivers an idea of their location in the cycle.

Flashing phase: There are many ways in which all or portions of messages can be flashed in an attempt to draw driver attention. One method is to flash the entire display for a one-phase message. Research (4, 5) in laboratory and simulator settings disagreed with regard to the effects on comprehension and reading time. In the laboratory, comprehension was not affected, but reading times were significantly longer when the message was flashing. In the simulator, comprehension was negatively affected for unfamiliar drivers, but reading times were not affected. Full-phase flashing messages are not recommended because of this disagreement in research results.

Flashing line: Another flashing method is to flash one line of a message. Research in laboratory and simulator settings (4, 5) showed that comprehension levels and reading times were both negatively affected by this method. Thus, flashing one line is not recommended.

Alternating line: In alternating-line messages, a portion of the message is held constant between the two phases (usually the first two lines) while the other portion is alternated between two pieces of information (usually the third line). Research (4, 5) on this method showed that although comprehension was not affected, reading times greatly increased.

Looming: In a study by Greenhouse (3), looming was shown to negatively affect some driver demographics more than others. However, it did not help any group of drivers comprehend messages. It also seemed to function as an additional driver distraction and a negative effect on intelligibility.

Design Issues

None.

Cross References

Composing a Message to Maximize Comprehension, 19-8

Key References

1. Dudek, C.L. (1992). *Guidelines on the Use and Operation of Changeable Message Signs*. (FHWA-TX-92-1232-9). College Station: Texas Transportation Institute.
2. Dudek, C.L. (2004). *Changeable Message Sign Operation and Messaging Handbook*. (FHWA-OP-03-070). College Station: Texas Transportation Institute.
3. Greenhouse, D. (2007). *Optimizing Comprehension of Changeable Message Signs (CMS)*. (UCB-ITS-PRR-2007-24). Berkeley: University of California Partners for Advanced Transit and Highways (PATH).
4. Dudek, C.L., and Ullman, G.L. (2002). Flashing messages, flashing lines, and alternating one line on changeable message signs. *Transportation Research Record*, 1803, 94-101
5. Dudek, C.L., Schrock, S.D., and Ullman, G.L. (2005). *Impacts of Using Dynamic Features to Display Messages on Changeable Message Signs*. (FHWA-HOP-05-069). Washington, DC: FHWA.

CHANGEABLE MESSAGE SIGNS FOR SPEED REDUCTION

Introduction

CMSs for speed reduction refers to situations in which a reduction in the speed of the traffic flow is desirable due to potential hazards, work zones, adverse weather conditions, incident control, or heavy congestion. Applications that are temporary or variable in nature are the primary candidates for using a speed-reduction CMS. Areas that experience recurring heavy peak traffic also can benefit from the proper application of a speed-controlling CMS.

Design Guidelines

General CMS Applications for Speed Reduction:

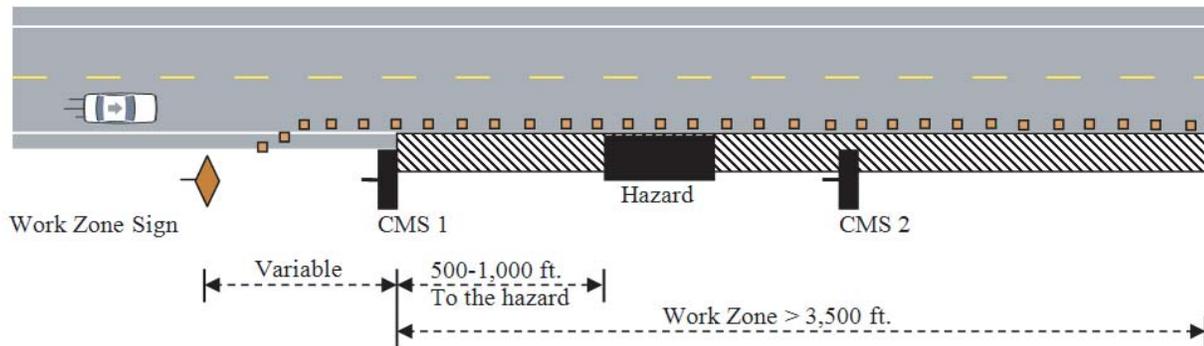
- Provide a reason for the reduced speed.
- Limit the use of safety campaign messages.
- Use CMS with radar for speed reduction:
 - “You Are Speeding/Slow Down” is an effective message for speeders (5).
 - “Your Speed/XX mph” is the MUTCD-approved text for displaying approach speeds.

Work Zone CMS Applications for Speed Reduction:

- In work zones over 3500 ft, use a second CMS partway through.
- For extended work (i.e., 1 year), use CMS for the project opening days and after major condition changes. Use passive controls at other times.
- Place the first CMS 500-1000 ft upstream from the hazardous location within the work zone after the first advance sign.
- Place signs away from other work zone signs, ramps, intersections, or lane-closure tapers.



SIGN PLACEMENT IN A WORK ZONE



Source: adapted from the MUTCD (6)

MAXIMUM SPEED REDUCTIONS IN WORK ZONES

Roadway Type	Speed Reduction (mi/h)
Rural two-lane, two-way highway	10-15
Rural freeway	5-15
Urban freeway	5-10
Urban arterial	10-15

Source: Richards and Dudek (4)

Discussion

General applications: Speed-reduction CMSs are used to reduce speeds during a wide range of events such as potential hazards, adverse weather conditions, traffic incidents, and heavy congestion. When CMSs are provided to reduce driver speeds, compliance is increased when a reason for the reduced speed is displayed (1). These signs are still effective after 7 weeks of exposure, continuing to cause significant speed reductions (2). In a simulator study by Jamson and Merat (3), little change in driver behavior was observed when the safety campaign message “Watch Your Speed” was displayed (maximum 0.5 mi/h speed reduction). However, it was found using eye-tracking data that drivers continued to look at CMSs along the route even though the message was repeated. Drivers who witnessed 33% of the CMSs on the route displaying safety campaign messages changed lanes significantly faster in response to an incident message than those who saw either all blank CMSs or 100% of the CMSs showing safety messages. These drivers also spent significantly more time looking at the incident message than any other group. An FHWA Policy Memorandum states that driver safety campaign messages should be limited to a few weeks so that drivers do not begin to ignore them (see “When to Use Changeable Message Signs” on page 19-2).

CMSs can also use radar to reduce speeds. Garber and Srinivasan (2) refer to a number of studies that show CMS with radar to be effective in reducing passing vehicle speeds. The message “You Are Speeding/Slow Down” proved to be the most effective message for reducing speeds (5). This message reduced average speeds, 85th percentile speeds, and traffic speed variance by statistically significant amounts. The MUTCD states that for these signs, the legend “Your Speed/XX mph” or something similar should be shown (6).

Work zone applications: CMSs have a limited range of effectiveness. The first CMS should be positioned 500 to 1000 ft upstream from the hazard in a work zone to give drivers time to react before reaching that hazard. However, this distance cannot be too long because drivers need to remember the message and maintain the reduced speed when they reach the hazard. In longer work zones, drivers tend to increase their speeds when they near the end of the zone, far away from the first CMS (2). Thus, if hazards continue to exist throughout a long zone, a second CMS may be needed.

The visibility and prominence of CMSs are important. Ideally, drivers will not be overloaded with information and will have sufficient available attention to focus on the CMS (4). Thus, the guidance is to place the CMS away from work zone signs, and out of high driver workload areas such as ramps, intersections, or lane-closure tapers.

Credibility is a general issue with CMSs that also applies to the application of CMSs in work zones. The selection of an unreasonably low speed causes drivers to lose respect for the signs, which leads to a loss of credibility (4). This loss of credibility can lead to reduced effectiveness of signs at other sites as well.

Richards and Dudek (4) report that drivers will only slow down a limited amount regardless of the posted limit. The reductions in average work zone speeds were found to be 5-20 mi/h, depending on the site. Thus, Richards and Dudek suggest maximum speed reductions in work zones as shown in the table on page 19-12.

Design Issues

Speed reductions as supported by CMSs can cause reductions in roadway capacity and congestion (4).

Cross References

Changeable Message Signs, 13-6

When to Use Changeable Message Signs, 19-2

Displaying Messages with Dynamic Characteristics, 19-10

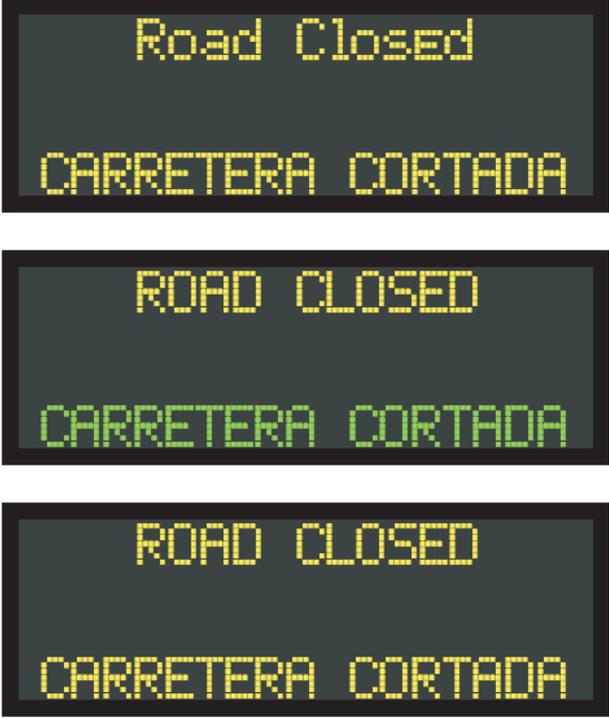
Key References

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6. FHWA (2009). *Manual on Uniform Traffic Control Devices for Streets and Highways*. Washington, DC.

PRESENTATION OF BILINGUAL INFORMATION

Introduction

Bilingual information refers to information that is presented in more than one language on CMSs. Drivers spend 10% to 15% more time reading bilingual than monolingual signs if they have more than 1 line in each language (*I*). However, in areas with large culturally diverse populations or areas with heavy international tourism, signs that present messages in more than one language may be required. Presenting bilingual information on a sign can increase reading times for monolingual and bilingual drivers. It is important to minimize this increase in reading times to reduce driver distraction.

Design Guidelines	
Guideline	Example (adapted from Jamson (<i>I</i>))
<ul style="list-style-type: none"> • Group lines by language rather than content <ul style="list-style-type: none"> – Display the most widely spoken language first 	
<ul style="list-style-type: none"> • Distinguish between languages on signs with two or more lines of text per language by using: <ul style="list-style-type: none"> – Case: display one language in all uppercase and the other in initial case (first letters of words capitalized) – Color: display one language in one color and the other in a different color – Spacing: leave a row blank between message lines in different languages 	
<div style="display: flex; justify-content: space-between; width: 100%;"> <div style="width: 33%; border-top: 1px solid black; border-left: 1px solid black; border-right: 1px solid black; height: 15px;"></div> <div style="width: 33%; border-top: 1px solid black; border-left: 1px solid black; border-right: 1px solid black; height: 15px;"></div> <div style="width: 33%; border-top: 1px solid black; border-left: 1px solid black; border-right: 1px solid black; height: 15px;"></div> </div>	
<p>Based Primarily on Expert Judgment</p>	<p>Based Equally on Expert Judgment and Empirical Data</p>
	<p>Based Primarily on Empirical Data</p>

Discussion

Reading response time for one line of relevant text on a two-line bilingual sign is not significantly different than reading response time for a one-line monolingual sign (*I*). Also, none of the demarcation techniques for the different languages made an impact on reading times for two-line bilingual signs. However, reading response times for two lines of relevant text on a four-line bilingual sign are significantly longer than reading response times for a two-line monolingual sign. The time required to read two lines of relevant text on a four-line bilingual sign is comparable to the time required to read four lines on a monolingual sign. Thus, introducing two lines of a second language strongly impacts reading performance. This impact can be mitigated through any of the demarcation techniques of color, case, or spacing.

Learning and expectancy effects were tested for case, color, and language order (*I*). Case showed neither effect, suggesting that drivers did not notice that it was being used to distinguish between languages. Color showed only expectancy, meaning that reading times did not decrease as more signs were viewed with the same color pattern, but times significantly increased when that pattern reversed. Language order showed both effects, showing that drivers learned the pattern and then were confused when it changed. These results speak to the effectiveness of different demarcation methods as well as the importance of consistency across bilingual message signs in an area.

Reading time is minimized when the dominant language of the driver is positioned first on the sign, for signs containing either one or two lines of relevant text per language (*I*). This finding has also been verified for static signs in both English/Welsh and English/French. The effect is greater for monolingual readers, based on bilingual readers in the English/French study seeming to respond to whichever language was first on the sign.

The studies that are cited on bilingual messages were performed using English and Welsh, which have identical character sets. Identical character sets lead drivers and study participants to attempt to read both sets of messages before finding one illegible (*2*). Results may not hold for bilingual signs displaying languages that use more distinctive character sets. Additionally, most of the guidance provided above is based upon a single, computer-based study.

Design Issues

Multiple methods were suggested by Jamson (*I*) for distinguishing between messages in different languages. Although the methods were proven to provide benefits for drivers, care should be used when applying some of these techniques. When the languages are distinguished by color, the colors selected should have neutral or equal meaning to drivers (*I*). For example, red can imply urgency, causing drivers to perceive the message in one language as more urgent. The colors should also have equal luminance in changing light and weather conditions. Language differentiation by case has disadvantages as well. Some studies indicate that mixed font is easier to read, while words written in all capital letters could be seen as higher priority. Also, displaying lowercase letters requires more space on the CMS to accommodate the descenders. Providing a blank row between languages has been shown to improve glance legibility (*I*). The greatest benefit was provided to monolingual drivers, especially when their language was not dominant. Multiple methods can be used concurrently to distinguish between languages; however, these effects were not studied.

An additional issue is the splitting of bilingual messages into multiple phases. The phase guidelines from Determining Appropriate Message Length (page 19-6) should be taken into consideration. Jamson (*I*) found that if a four-line bilingual message is split into two phases in such a way that each phase contains one line in each language that does not make sense alone, reading times for both phases increase significantly. The concern with presenting the entire message in one language and then another language (each phase is monolingual) is that drivers may encounter the sign when it is not displaying a language that they understand while other drivers, who could comprehend the message, may already be reacting in ways that are unexpected (*I*).

Cross References

Determining Appropriate Message Length, 19-6

Key References

1. Jamson, S.L. (2004). Evaluation of techniques to improve the legibility of bilingual variable message signs. *Advances in Transportation Studies: An International Journal, Section B, 4*, 71-88.
2. Jamson, S.L., Tate, F.N., and Jamson, A.H. (2001). Bilingual variable message signs: a study of information presentation and driver distraction. *Driving Assessment 2001: The First International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, 153-158.



CHAPTER 20

Markings

Visibility of Lane Markings	20-2
Effectiveness of Symbolic Markings	20-4
Markings for Pedestrian and Bicyclist Safety	20-6
Post-Mounted Delineators	20-8
Markings for Roundabouts	20-10

VISIBILITY OF LANE MARKINGS

Introduction

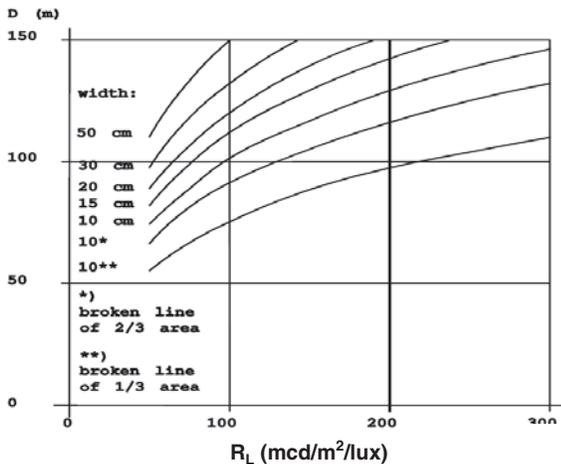
Visibility of lane markings refers to the ease with which drivers can see and follow longitudinal lane markings. Lane markings are designed for a certain *preview time*, the amount of time that drivers look ahead on the roadway. This preview time is affected by the distance at which drivers can see markings, which is a function of retroreflectivity and marking width. Different lane marking patterns and colors can have different meanings and regulate different driver actions, such as exiting, lane changing, passing, and maintaining roadway position. For this and other safety reasons, it is important that drivers are able to see and understand lane markings from an appropriate distance.

Design Guidelines	
Factor	Guideline
Preview Time	<ul style="list-style-type: none"> Absolute minimum preview time = 3 s Recommended preview time = 5 s
Marking-Specific Luminance	<ul style="list-style-type: none"> Minimum Dark Luminance = 100 mcd/m²/lux Minimum (adjusted for dirt) Dark Luminance = 121 mcd/m²/lux
Marking Width	<ul style="list-style-type: none"> If there is concern about the visibility of the markings, use a 6 or 8 in. marking width instead of the standard 4 in.

mcd = millicandela

MATHEMATICAL ESTIMATION OF VISIBILITY DISTANCE BASED UPON MARKING RETROREFLECTIVITY AND WIDTH (I) (MODELS ARE FOR YOUNG DRIVERS AND DO NOT CONSIDER GLARE)

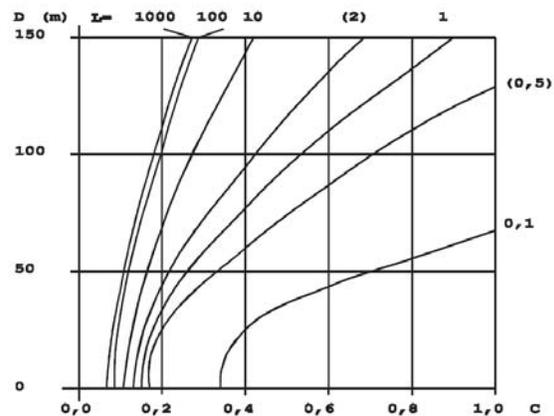
Visibility distance (D) for longitudinal road markings in high-beam illumination



Where:

- R_L is the coefficient of retroreflected luminance (and R_L (road) = 15 mcd/m²/lux)
- Luminous intensity is constant towards the road markings (10,000 cd)

Visibility distance (D) for a continuous road marking of 10 cm width in uniform illumination (simulated daylight)



Where:

- C is the contrast ratio between the pavement marking and the roadway
 - L is the luminance in cd/m²
- (Note: Road surface luminance levels in Europe typically range from 0.5 to 2 cd/m².)

Discussion

Preview time: There is some disagreement regarding the minimum amount of preview time that should be provided for drivers. Rumar and Marsh (2) determined through a literature review that a 5-s preview time accommodates proper anticipatory steering behavior, safe steering on roads that are not straight, and the minimum long-range preview time. However, the same review revealed that the Commission Internationale de l'Eclairage (CIE) recommended a lower bound of 3 s for preview time. Schnell and Zwahlen (3) suggest adding an 85th percentile eye-fixation duration of 0.65 s to the 3-s minimum chosen by the CIE to account for the time required for the driver to see and process the marking information. This value is also supported by the COST study, which found that drivers initially had a 2.18-s average preview time, but when the visibility of road markings in the on-road study was increased, the preview times increased to 3.15 s on average (1). Additionally, drivers increased their speed very little to compensate for the increased marking visibility (equivalent to approximately 0.1 s of the time increase) and thus preserved the remainder of the preview time. Therefore, this recommendation is to provide a 5-s preview time when possible, but a 3-s preview time as an absolute minimum.

Retroreflectivity: Pavement line retroreflectivity affects the distance from which drivers can view a pavement marking. In a study using subjective observer ratings, Graham, Harrold, and King (4) found that 85% of participants 60 years of age and older rated markings with retroreflectance values of 100 mcd/m²/lux or greater as being adequate or more than adequate when viewed under nighttime conditions. They also calculated a 21% increase in this value (to 121 mcd/m²/lux) to account for occluded light due to dirty windshields and headlights for vehicles that are reasonably maintained. Additionally, more than 90% of the young subjects rated a marking retroreflectance of 93 mcd/m²/lux as adequate or more than adequate for night conditions. In another study utilizing subjective ratings, Ethen and Woltman (5) also found 100 mcd/m²/lux to be the minimum for dark conditions. Note that the luminances that were rated as acceptable were much higher (300 to 400 mcd/m²/lux) in comparison to the minimum values (5).

Marking width: The standard width for most longitudinal pavement markings is 4 in. In a survey of state highway agencies, 58% have used markings that are wider than the standard 4-in. marking for centerline, edge line, or lane line applications (6). The data are limited regarding the effectiveness of these markings. However, when surveyed, drivers placed high priority on the quality of pavement markings (6). A variety of studies have shown that when wider than standard pavement markings were used, mean lateral placement was more centered, fewer lane departures on curves were observed, and lanekeeping in low-contrast situations improved (6). Gates and Hawkins (6) concluded that these wider markings show benefits for locations where a higher degree of lane or roadway definition is needed, such as in horizontal curves, roadways with narrow or no shoulders, and construction work zones. Although many of these findings result from a test of one width (either 6 or 8 in.), Gibbons, McElheny, and Edwards (7) found that visibility distance increased for a 6-in. width, but not correspondingly for the 8-in. width. This finding suggests that there may be a threshold where performance does not significantly increase with an increase in line width.

Design Issues

Problems with glare are more pronounced with the elderly, because optical deficiencies of the eye increase with age. In addition to the temporal visual impairments, glare can cause discomfort and fatigue. In a simulator study with a 4-in. edge line and opposing headlamp glare conditions, subjects aged 65 to 80 required an increase in contrast of 20% to 30% over a younger sample to correctly discern downstream curve direction. To accommodate less capable drivers, the study suggests an increase in stripe brightness of 300% (8).

Gates, Chrysler, and Hawkins (9) found that short-range driving performance, including activities such as lane positioning, is more reliant on driver peripheral vision than foveal vision. Wider markings are believed to provide a stronger signal to the driver's peripheral vision over standard width markings, thereby improving driver comfort and short-range performance. Most studies about marking width involve long-range driving tasks such as end detection, which are performed by foveal vision.

Cross References

None.

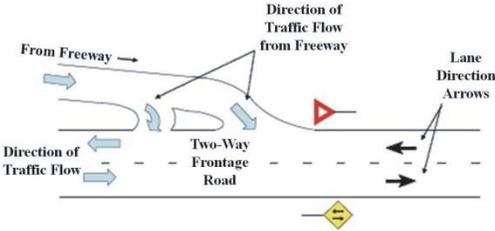
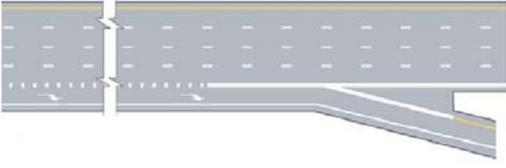
Key References

1. Commission Internationale de l'Eclairage (1999). *COST 331: Requirements for Horizontal Road Marking*. Luxembourg: Office for Official Publications of the European Communities. Retrieved from <ftp://ftp.cordis.europa.eu/pub/cost-transport/docs/331-en.pdf>.
2. Rumar, K., and Marsh, D.K., II (1998). *Lane Markings in Night Driving: A Review of Past Research and of Present Situation* (UMTRI-98-50). Ann Arbor: University of Michigan Transportation Research Institute.
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9. Gates, T., Chrysler, S., and Hawkins, H.G. (2002). Innovative visibility-based measure of effectiveness from wider longitudinal pavement markings (VIS2002-30). *Proceedings of the 16th Biennial Symposium on Visibility and Simulation*. Retrieved from <http://arrow.win.ecn.uiowa.edu/symposium/DraftPapers/VIS2002-30.pdf>.

EFFECTIVENESS OF SYMBOLIC MARKINGS

Introduction

Effectiveness of symbolic markings refers to the degree to which drivers follow and understand text or symbols on the roadway. A major component of pavement markings is *horizontal signing*, which is composed of sign text that is painted on the roadway. Horizontal signing is effective because drivers spend most of their time scanning the roadway in front of their vehicle near the horizon (*I*). Because drivers are already looking at the pavement, they are likely to see information there more quickly, preventing the need for an eye movement away from the road. Additionally, the pavement can be a good location to provide lane-specific information.

Design Guidelines				
Marking Goal	Do this:		Do not do this:	
Reduce speeds in horizontal curves	 Curve arrow and "50 mph" text	 "Curve 55 mph" text	 Transverse lines	 "Curve Ahead" text
Reduce wrong-way movements on two-way frontage roads	 Lane direction arrows on a two-way frontage road by an off-ramp		N/A	
Provide route guidance information for lane drops	 Route shield in the exiting lane		 Route name text in the exiting lane	
	 Pavement marking arrows (in addition to traditional lane drop markings)		N/A	
Based Primarily on Expert Judgment		Based Equally on Expert Judgment and Empirical Data		Based Primarily on Empirical Data

Discussion

Speed reduction in horizontal curves: In an on-road study of horizontal signing to reduce speeds before horizontal curves, Chrysler and Schrock (1) found that the text “Curve 55 mph” reduced speeds on a rural road by approximately 4 mi/h more than the control treatment. Although this finding was not statistically significant, the benefit from this marking was greater than for the “Curve Ahead” text (which did not cause a significant reduction). When the curve arrow and “50 mph” text were tested on an urban roadway, vehicles significantly reduced their speeds by 10% at the entrance to the curve. There was also an 11% to 20% reduction in vehicles exceeding the speed limit. Note that the curve arrow and “50 mph” text were tested in a section of the road following a vertical crest, so the arrow provided additional information about the direction of the curve after drivers came over the crest. Another option if advisory speeds cannot be displayed is the text “SLOW” with a curve arrow. Retting and Farmer (2) tested this marking on a suburban road and found that it significantly reduced the percentage of drivers exceeding the speed limit by more than 5 mi/h during the daytime and late night time frames, but not during the evening. Overall, the markings that provided advisory speeds or an action performed most effectively.

The results of transverse line treatments have been mixed. Chrysler and Schrock (1) found that a series of three pairs of transverse lines near the middle of the lane did not cause a significant speed reduction. However, Katz (3) found that transverse lines at the lane edges resulted in speed reductions, which were significant on interstate and arterial roadways, but not rural roadways. Note that the treatments differed in multiple ways. Chrysler and Schrock (1) attempted to create a “visual rumble strip,” which would appear in the driver’s foveal vision, on a rural road. Katz (3) used markings at the lane edges, which would appear in the driver’s peripheral field of view and create the illusion of higher than actual speed.

Wrong-way movements on two-way frontage roads: Chrysler and Schrock (1) tested the implementation of lane direction arrows on a frontage road in Texas. The use of one-way and two-way frontage roads is widespread in Texas, potentially increasing the probability of wrong-way movements. Lane direction arrows were placed on the frontage road, 120 ft from the gore area of the exit onto the road. With the arrows installed, the rates of wrong-way driving maneuvers and conflicts were significantly reduced by 90% and almost 100% respectively. This overwhelming reduction in wrong-way driving indicates that the treatment can have a beneficial safety influence on traffic at locations where drivers may be confused about appropriate lane selection.

Lane drops: In a study of route guidance information regarding lane drops, Chrysler and Schrock (1) surveyed drivers about route markers. The majority (94%) of respondents preferred the route shield over the route name text. However, 29% to 48% of drivers thought that the marking indicated the route they were currently on rather than the upcoming exit. Therefore, route shields may be effective when used with other lane drop signs/markings. Fitzpatrick, Lance, and Lienau (4) tested another lane drop indicator: pavement marking arrows. With the addition of pavement marking arrows, erratic maneuvers such as lane changes through the gore and attempted lane changes decreased. Drivers continuing on the main route moved out of the exit lane earlier. Although these results were only significant for two out of the three sites tested, the other site had a lane drop only 1.6 km (1 mi) long, and vehicles may have shifted through the exit lane upstream of the study segment.

Design Issues

Horizontal signing has two issues that can be broadly applied: visibility of the markings and durability of the materials on the travel lane. Horizontal markings viewed during daytime must contrast with the road surface. White markings may not provide an adequate contrast for symbol recognition or word legibility when viewed against a concrete or worn asphalt surface. Conversely, nighttime visibility is affected by the durability of the optical elements presented in the marking material, typically glass beads. Other visibility limitations can be found in shortened headways due to traffic congestion that may not be large enough for full horizontal sign viewing. Horizontal signs should have large simple components and should be visually unique to the highest possible degree. Proper application using text or symbols should minimize the use of abbreviations, keeping the symbols simple and legible. By limiting the application to critical locations, drivers will be able to recognize these signs as an added warning or caution (5).

Chrysler and Schrock (1) determined that when drivers are undergoing stressful driving conditions or situations where too much information is presented at one time, they will practice “load shedding” by ignoring the least important information and focusing on the more important tasks. Drivers will tend to look at the road more and at side or overhead-mounted signing less when “load shedding” takes place. This behavior increases the importance of horizontal signing in the area where drivers look most.

Cross References

None.

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MARKINGS FOR PEDESTRIAN AND BICYCLIST SAFETY

Introduction

Markings for pedestrian and bicyclist safety refers to pavement marking techniques to encourage safe practices for road sharing by vehicles, pedestrians, and bicycles. Pedestrian markings include crosswalks, which are defined as marked or unmarked extensions of sidewalks or shoulders across intersections (I). Crosswalks may also be located midblock, but only if marked. Bicycles and vehicles may utilize shared lanes on either rural or non-rural roadways. The purpose of markings in shared lanes is to notify users that the lane is shared and clearly define the positioning of the traffic flows.

Design Guidelines

RECOMMENDATIONS FOR INSTALLING MARKED CROSSWALKS AND OTHER PEDESTRIAN IMPROVEMENTS AT UNCONTROLLED LOCATIONS

Roadway Type (Number of travel lanes and median type)	Vehicle ADT ≤ 9,000			Vehicle ADT > 9,000 to 12,000			Vehicle ADT > 12,000 to 15,000			Vehicle ADT > 15,000		
	≤ 30 mi/h	35 mi/h	40 mi/h	≤ 30 mi/h	35 mi/h	40 mi/h	≤ 30 mi/h	35 mi/h	40 mi/h	≤ 30 mi/h	35 mi/h	40 mi/h
2 lanes	C	C	P	C	C	P	C	C	N	C	P	N
3 lanes	C	C	P	C	P	P	P	P	N	P	N	N
Multilane (≥ 4 lanes) with raised median	C	C	P	C	P	N	P	P	N	N	N	N
Multilane (≥ 4 lanes) without raised median	C	P	N	P	P	N	N	N	N	N	N	N

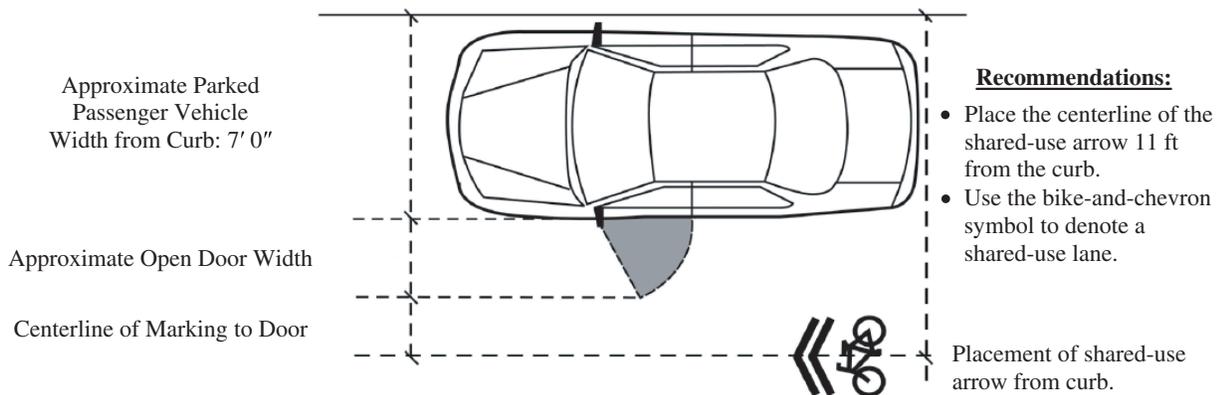
C: Candidate site for marked crosswalk. Marked crosswalk can be considered after an engineering study and confirmation of 20 pedestrian (or 15 elderly/child) crossings per peak hour.

P: Possible increase in pedestrian crash risk may occur if crosswalks are added without other crossing improvements; locations should be monitored and enhanced with other improvements if necessary before adding a crosswalk.

N: Marked crosswalks should not be added alone because pedestrian crash risk may increase; treatments such as traffic calming measures, traffic signals with pedestrian signals, or other crossing safety improvements should be considered.

Source: adapted from Zeeger et al. (1)

PLACEMENT OF RECOMMENDED SHARED-USE LANE SYMBOL FOR BICYCLISTS AND VEHICLES



Source: Birk, Khan, Moore, and Lerch (2)



Discussion

Crosswalks: Zeeger et al. (1) provide guidelines for the locations where marked crosswalks should be installed based upon a study of pedestrian crashes at marked and unmarked crosswalks. The guidelines apply to uncontrolled locations excluding school crossings. Crosswalks should not be installed in locations where additional pedestrian safety risks exist (e.g., poor sight distance, confusing designs) without other design features or traffic control devices (1). Crosswalks alone do not make crossings safer or guarantee that more vehicles will stop for pedestrians.

Nowakowski (3) found that there are three critical locations where potential vehicular-pedestrian conflict could occur: the mid-block crossing and the left and right turning lanes at an intersection. The difficulty for the driver is detecting pedestrians because visual scanning and attention are limited. It is recommended that parking be eliminated on the approach to uncontrolled crosswalks to improve vision between pedestrians and drivers. The Uniform Vehicle Code (4) specifies that parking should be prohibited within 20 ft of a crosswalk at an intersection (which could be increased to 30 to 50 ft in advance of a crosswalk on a high-speed road).

Design of the shared-use arrow: Shared-use arrows (also referred to as “sharrows”) on roadways attempt to reduce safety problems such as “dooring,” where bicyclists ride into parked vehicle doors when ajar; wrong-side riding; sidewalk riding; motorists squeezing out bicyclists; and other aggressive behaviors (2). Shared pavement markings can increase the percentage of bicyclists riding in the street, which can help reduce crashes with turning vehicles.

Two bicyclist surveys and an on-road study regarding a number of shared-lane markings were conducted in San Francisco (2, 5). The lane markings tested were bike-and-chevron (shown on the previous page), bike-in-arrow (bicyclist inside of an arrow outline), and a separated bike-and-arrow. During the on-road study, the bike-and-chevron marking significantly reduced sidewalk riding (by 35%) and wrong-way riding (by 80%). It also increased all distances between moving cars, cyclists, and parked cars. Overall, 60% of cyclists thought that the markings positively affected their sense of safety and preferred the bike-and-chevron marking by a 2:1 ratio. However, 30% of cyclists indicated that the markings tested meant that bikes have priority, rather than that the lane is shared.

The distance of the shared-use arrow from the curb is based upon parked vehicle width. Birk et al. (2) observed that the 85th percentile of car doors open 9 ft 6 in. from the curb, the average bicycle width is 2 ft, and 6 in. of “shy distance” is added between the open door and bicycle handlebars. In total, these distances indicate that the centerline of the pavement marking should be 11 ft from the curb.

Design Issues

Crosswalk lighting: In-roadway crosswalk warning lights can provide pedestrian safety benefits. With in-roadway warning lights: passing vehicle speeds decreased from 7% to 44% (6, 7), the percentage of drivers yielding to pedestrians increased during day and night by 26% to 162% (8, 9), and the percentage of drivers who saw the crosswalk, saw a pedestrian, and accurately stated the presence of the pedestrian increased by 13%, 25%, and 38%, respectively (8).

Shared lanes: Shared-use lanes often exist where there is too little space available to create a dedicated bicycle lane. When space is available, a bicycle lane or wide curb lane may be created; however, there is disagreement as to which is better. See Hunter, Stewart, Stutts, Huany, and Pein (10) for a discussion of each lane type.

Cross References

None.

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POST-MOUNTED DELINEATORS

Introduction

Post-mounted delineators (PMDs) are a type of marking device used to guide vehicles along a roadway. The AASHTO Green Book (1) specifies that delineators shall be retroreflective devices mounted above the roadway surface and along the side of the roadway in a series to indicate the alignment of the roadway. Delineators are particularly useful at locations where the alignment might be confusing or unexpected, such as at lane reduction transitions and/or curves (2). They are also useful at night and during adverse weather. Delineators may be used on long sections of highways or on short sections where there are changes in horizontal alignment. An important advantage of delineators is that they remain visible when the roadway is wet or snow covered.

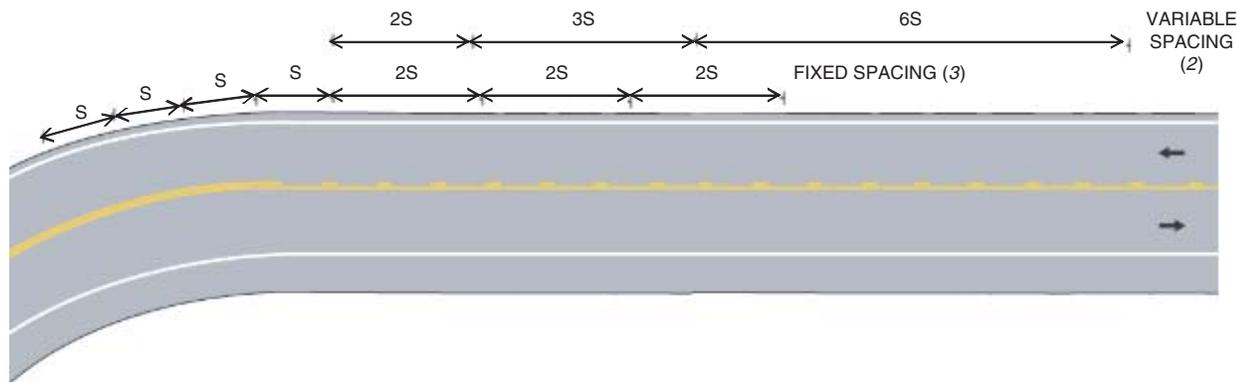
Design Guidelines

Spacing: Drivers respond similarly to fixed and variable spacing of delineators when perceiving curvature. Thus, either spacing method can be used for outlining the curve approach and departure segments.

MUTCD (2) RECOMMENDATIONS FOR DELINEATOR SPACING ON CURVES

Radius of Curve (ft)	50	115	180	250	300	400	500	600	700	800	900	1000
Approximate Spacing (S) on Curve (ft)	20	25	35	40	50	55	65	70	75	80	85	90

VARIABLE AND FIXED SPACING FOR CURVE APPROACHES AND DEPARTURES



Preview Times	Post-mounted delineators should be visible with a preview time of at least 5 s.
Number of Reflectors	There is no difference in curve perception between single and double delineators; thus, either is acceptable for curve delineation.
Color	Drivers are not aware of the varying meanings of differently colored delineators. If differently colored delineators are used, drivers should receive education as to their specific meanings.



Discussion

Spacing: Charlton (4) found that drivers' perceptions of speed and curvature appear to work at both a conscious (explicit) and unconscious (implicit) level. For this reason, curve warnings and delineation treatments that highlight the sharpness of the curve ahead or increase a drivers' momentary sense of their apparent speed appear to offer promise in allowing drivers to enter curves at a lower speed. Delineation treatments may also assist drivers with selecting and maintaining appropriate lane position while travelling throughout the curve.

Chrysler, Carlson, and Williams (3) found that drivers cannot distinguish between fixed and variable delineator spacing on the approaches to horizontal curves. The two types of spacing led to functionally equivalent curve perceptions. Thus, Chrysler et al. (3) recommend that the approach and departure delineator spacings be fixed at two times the appropriate curve spacing found in the MUTCD. This recommendation can save installation time without sacrificing safety. More specific information on spacing on horizontal curves can be found in the MUTCD.

Preview time: Rumar and Marsh (5) explained two complementary road guidance functions: short-range and long-range guidance. Long-range guidance (over 5 s of preview time) allows the driver to consciously predict the path of the roadway far in advance, drive smoothly, and avoid time-pressure situations. Rumar and Marsh (5) found that preview times provided by lane markings alone are well under a safety criterion of 5 s and thus concluded that current lane markings are not optimal for safe night driving. Good & Baxter (6) found the addition of PMDs tends to have a positive effect for long-range guidance, but have no effect on short-range guidance. To be usable for long-range guidance, PMDs should be visible at a preview time of at least 5 s (about 440 ft at 60 mi/h (140 m at 100 km/h)) under low-beam illumination.

Number of reflectors: Chrysler et al. (3) found that the perception of curvature is not affected by the number of reflectors on the delineator. However, the combination of one reflector and variable spacing leading up to the curve caused the perception of less curvature. Overall, Chrysler et al. (3) recommend that the MUTCD eliminate the distinction between the two types of delineators and define a standard delineator. Larger delineators could still be used for emphasis where necessary.

Color: Chrysler et al. (3) found that drivers do not understand the difference in placement for yellow and white delineators. Although response accuracy was poor for curve delineator color, when given a forced-choice question regarding crossover delineation, most drivers could recognize the correct color. This finding led to the recommendation of putting more emphasis on delineator color in driver education courses rather than altering the MUTCD.

Design Issues

Another use of delineators is to define the roadway leading up to a railroad grade crossing. At rural crossings without active warning devices, the lighting may be poor and drivers may be more reliant on auditory train signals to know if a train is approaching. However, these auditory signals may not be completely effective for drivers who are hearing impaired. Staplin, Lococo, Byington, and Harkey (7) found that approximately 30% to 35% of people aged 65 to 75 have a hearing loss, increasing to 40% for persons over the age of 75. The use of post-mounted delineators would help highlight to hearing-impaired drivers that railroad crossing is imminent.

Cross References

None.

Key References

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MARKINGS FOR ROUNDABOUTS

Introduction

Markings for roundabouts refers to pavement markings on the entrances to and exits from roundabout intersections. Roundabout intersections are defined by the MUTCD (1) as “circular intersections with yield control at entry, which permits a vehicle on the circulatory roadway to proceed, and with deflection of the approaching vehicle counter-clockwise around a central island.” Roundabout markings need to display clear information to incoming drivers to ensure the safe circulation of vehicles. Conflict points occur where one vehicle path crosses, merges, or diverges with or queues behind the path of another vehicle, pedestrian, or bicycle. Within roundabouts, fewer conflict points occur as compared to conventional intersections; hazardous conflicts such as right-angle and left-turn head-on crashes are eliminated. Single-lane approach roundabouts provide greater safety benefits than multilane approaches because there are fewer potential conflicts between road users, and pedestrian crossings are shorter. Robinson et al. (2) note that lower vehicle speeds entering and in the roundabout provide drivers more time to deal with potential conflicts.

Design Guidelines

Luminance contrast between the curb markings and the pavement should be:

- 2.0 or higher for roundabouts with overhead lighting
- 3.0 or higher for roundabouts without overhead lighting

Luminance contrast is calculated by:

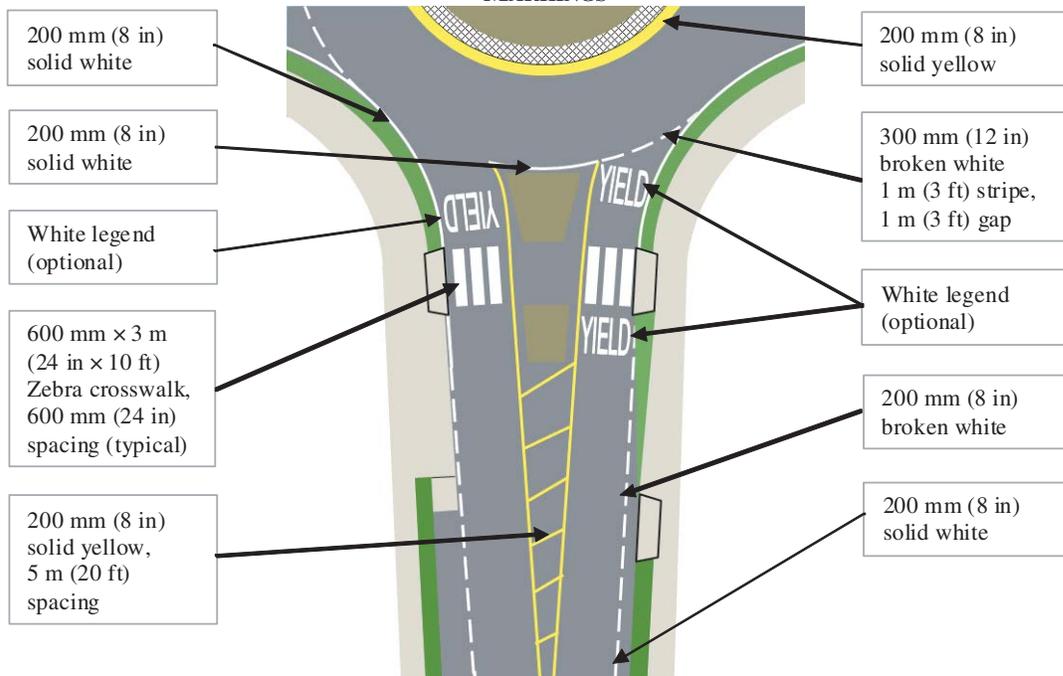
$$\text{Luminance contrast} = \frac{L_{\text{stripe}} - L_{\text{pavement}}}{L_{\text{pavement}}}$$

Where:

L_{stripe} = the luminance of the pavement marking

L_{pavement} = the luminance of the pavement

RECOMMENDED ROUNDABOUT PAVEMENT MARKINGS



Source: adapted from Robinson et al. (2)



Discussion

Luminance contrast: Staplin, Lococo, Byington, and Harkey (3) recommended that retroreflective markings should be applied to the sides and tops of the curbs on the splitter islands and the central island. The recommended curb contrast levels refer to the contrast between these markings and the pavement. For roundabouts with overhead lighting, a contrast of 2.0 or higher was recommended. For roundabouts without overhead lighting, a contrast of 3.0 or higher was recommended. Staplin et al. (3) state that the luminance measurements should be taken at night, using low-beam headlamp illumination from a passenger vehicle, at a 5-s preview distance upstream of the intersection.

Recommended roundabout pavement markings: The pavement markings in the figure shown on the previous page are from *Roundabouts: An Informational Guide* (2) and differ slightly from those included in the MUTCD (1). Several markings are usually placed within roundabouts to help regulate the flow and speeds of oncoming vehicles. Such markings include broken white lines, solid white lines, solid yellow lines, crosswalk markings, and roadway marking text “Yield”. Roundabout lane markings follow the logic that yellow lines denote opposing traffic and white lines denote traffic moving in the same direction. A solid white line marks the right edge of the road. Additionally, normal or fish-hook lane-use arrow pavement markings may be used on roundabout approaches as defined by the MUTCD (1).

A fundamental difference between roundabouts and traditional intersections is the continuous flow of traffic at roundabouts vs. the alternating of opposing traffic flows at traditional intersections (2). This difference creates different visual demands at roundabouts, where the driver is not given the right-of-way by traffic signals. Also, pedestrians are not given signaled time to cross roundabouts. The placement of crosswalks at roundabouts is further back in order to move pedestrians out of the continuous traffic flow. This placement also reduces the visual demands for drivers who otherwise would be required to look for approaching vehicles from the left and pedestrians from the right as they entered the roundabout. With the crosswalk further from the circular area, pedestrians cross in the drivers’ forward field of vision (2).

Crosswalks: It is important that the crosswalks preceding the roundabout have a high degree of visibility because they are set back from the yield line. Zebra crossings are recommended because they are highly visible, distinguish the intersection from signalized intersections, and are less likely to be confused with the yield line than transverse crosswalks (2).

Bicycle lanes: The MUTCD (1) states that bicycle lane markings shall not be included within the circulatory roadway of a roundabout. The figure on the previous page shows how Robinson et al. (2) suggest that bicycle lanes should be included on an approach to a roundabout. This design provides a curb ramp where the bicycle lane ends to allow bicyclists to transition as a pedestrian to the sidewalk. Robinson et al. (2) state that, at roundabouts, bicyclists can circulate with other vehicles, travel as a pedestrian on the sidewalk, or use a separate shared-use facility for pedestrians and bicyclists where provided.

Design Issues

Stopping sight distance: Stopping sight distance should be provided at every point within a roundabout and on each entrance and exit (2). On the approach to the roundabout, vehicles need to have a stopping sight distance to the crosswalk and the yield line. When circulating, vehicles need to be able to see that same distance around the circle. When exiting the roundabout, vehicles need a stopping sight distance to the crosswalk. The intersection sight distance is the distance that a driver without the right-of-way needs in order to see and react to conflicting vehicles before entering the roundabout (2). Because of the geometry of the roundabout, the intersection sight distance implies drivers must look over/through part of the central island. This requirement poses restrictions on the height and placement of objects and landscaping in that island; appropriate sight distance requires a clear central island. However, Robinson et al. (2) recommends that only the minimum intersection sight distance should be provided because excessive sight distance can lead to higher vehicle speeds, reducing safety for all users.

Cross References

None.

Key References

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Tutorials

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Tutorial 1: Real-World Driver Behavior Versus Design Models

Much of the information on sight distance presented in Chapter 5 reflects the application of empirically derived models to determine sight distance requirements. Such models, while valuable for estimating driver behavior across a broad range of drivers, conditions, and situations, have limitations.

This tutorial discusses how driver behavior as represented in sight distance models may differ from actual driver behavior. The design models presented in Chapter 5 use simplified concepts of how the driver thinks and acts. This simplification should not be viewed as a flaw or error in the sight distance equations. These models are a very effective way of bringing human factors data into design equations in a manner that makes them accessible and usable. After all, the intent of a sight distance equation is not to reflect the complexities of human behavior but to bring what we know about it into highway design in a concise, practical way. However, like any behavioral model, models for deriving sight distance requirements are not precise predictors of every case and there may be some limitations to their generality. Therefore, having an understanding of certain basic principles of human behavior in driving situations is useful to better interpret these models and to understand how they may differ from the range of real-world driving situations.

Sight distance formulas for various maneuvers (presented in Chapter 5) differ from one another, but they share a common simple behavioral model as part of the process. The model assumes that some time is required for drivers to perceive and react to a situation or condition requiring a particular driving maneuver (i.e., PRT), which is followed by some time (i.e., MT) and/or distance required to execute the maneuver. Sight distance equations for some maneuvers may contain additional elements or assumptions; however, all have this basic two-stage model somewhere at their core.

The two equations that follow show two versions of the general, two-component model. In both versions, the first term shows the distance traveled during the PRT component and the second term shows the distance traveled during the MT component. The difference is that the first equation shows a case where the distance traveled while executing the maneuver is based on the *time* required to make that maneuver (for example, the time to cross an intersection from a Stop), while the second equation shows a case where the distance traveled while executing the maneuver is based directly on the *distance* required to complete the maneuver (for example, braking distance for an emergency stop). For both forms of this general equation, vehicle speed (V) influences the second (MT) component.

The general form of the sight distance equation is:

$$d_{SD} = kVt_{prt} + kVt_{man}, \text{ where maneuver time is input or}$$

$$d_{SD} = kVt_{prt} + d_{manV}, \text{ where maneuver time is input}$$

Where:

d = required sight distance

V = velocity of the vehicle(s)

t_{prt} = PRT

t_{man} = MT

d_{manV} = distance required to execute a maneuver at velocity V

k = a constant to convert the solution to the desired units (feet, meters)

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For the most part, these references and the other research provided information about which tasks were involved in a given segment, but not complete information about the specific information-processing subtasks. To determine this information, the details about the information-processing subtasks and any other necessary information were identified by the authors based on expert judgment and other more general sources of driving behavior and human factors research (e.g., Groeger, 2000; Salvendy, 1997; Underwood, 1998).

Tutorial 4: Determining Appropriate Clearance Intervals

Methods for determining appropriate clearance interval length vary from agency to agency, and there is no consensus on which is the best method. The Institute for Transportation Engineers recommends several procedures for determining clearance interval duration in a 1994 informational report (see ITE, 1994) on signal change interval lengths. These methods include:

1. A rule of thumb based on approach speed, such as this one presented in the ITE *Traffic Engineering Handbook* (Pline, 1999):
 - Yellow change time in seconds = operating speed in mi/h/10
 - Red clearance interval = 1 or 2 s
2. Formulas for calculating interval lengths based on site, vehicle, and human factors characteristics, such as this equation (from Pline, 1999):

$$CP = t + \frac{V}{2a \pm 64.4g} + \frac{W + L}{V}$$

Where:

CP = non-dilemma change period (change + clearance intervals)

t = perception-reaction time (nominally 1 s)

V = approach speed, m/s [ft/s]

g = percent grade (positive for upgrade, negative for downgrade)

a = deceleration rate, m/s² (typical 3.1 m/s²) [ft/s² (typical 10 ft/s²)]

W = width of intersection, curb to curb, m [ft]

L = length of vehicle, m (typical 6 m) [ft (typical 20 ft)]

3. A uniform clearance interval length—Various studies report that uniform value of 4 or 4.5 s for the yellow change interval length throughout a jurisdiction is sufficient to accommodate most approach speeds and deceleration rates. Refer to *Determining Vehicle Signal Change and Clearance Intervals* (ITE, 1994) for more discussion on this.

The *Manual on Uniform Traffic Control Devices* (FHWA, 2007) states that a yellow change interval should be approximately 3 to 6 s, and the *Traffic Engineering Handbook* (Pline, 1999) states that a maximum of 5 s is typical for the yellow change interval. The red clearance interval, if used, should not exceed 6 s (FHWA, 2007), but 2 s or less is typical (Pline, 1999). The traffic laws in each state may vary from these suggested practices. ITE recommends that the yellow interval not exceed 5 s, so as not to encourage driver disrespect for signals.

Tutorial 5: Determining Appropriate Sign Placement and Letter Height Requirements

When determining the appropriate sign placement, it is important to consider a number of driver-related factors. The *Traffic Control Devices Handbook* (Pline, 2001) describes a process that utilizes these factors and is the basis for the steps described below. This method is mostly focused on guide and informational sign applications.

Step 1. Calculate the Reading Distance

The *reading distance* is the portion of the travelling distance allotted for the driver to read the message, based upon the time required to read it (reading time). The *Traffic Control Devices Handbook* outlines two methods for calculating the reading time. The first method, used by the Ontario Ministry of Transportation, is described in the following three steps:

1. Allocate 0.5 s per word or number and 1 s per symbol, with a 1-s minimum for the total reading time. This time should only include critical words. Drivers do not need to read every word of each destination listed on a sign to find the one they are looking for. For example, assume they are reading a sign with two destinations: Mercer St. and Union St., each with a direction arrow. Drivers only need to read the word Mercer to realize that is not the street they are looking for and the word Union to know that is their destination. They then only need to look at the arrow for Union St.
2. “If there are more than four words on a sign, a driver must glance at it more than once, and look back to the road and at the sign again. For every additional four words and numbers, or every two symbols, an additional 0.75 s should be added to the reading time.” (Ontario Ministry of Transportation Traffic Office, 2001)
3. If the maneuver does not begin before the driver reaches the sign, add 0.5 s to the reading time. This extra time is to account for the extreme viewing angle immediately before the driver passes the sign, which prohibits reading. If the maneuver has already begun, the driver does not need to continue to read the sign, and thus does not need more time.

These three steps are summarized in Table 22-7.

Table 22-7. Three-step method for calculating base reading time.

Step 1	Step 2	Step 3
Base Reading Time (BRT)	Are there more than 4 words?	Does the maneuver initiate before passing the sign?
BRT (s) = $0.5x + 1y$ where: x = the number of critical words/ numbers in the message y = the number of critical symbols in the message	Yes: Add time based on the BRT $2 < \text{BRT} \leq 4$ Add 0.75 s $4 < \text{BRT} \leq 6$ Add 1.50 s $6 < \text{BRT} \leq 8$ Add 2.25 s ...etc	Yes: Add 0 s
	No: Add 0 s	No: Add 0.5 s

Another method for calculating reading time, cited in previous studies, applies to complex signs in high-speed conditions. The formula provided is:

$$\text{Reading Time (s)} = 0.31 (\text{Number of Familiar Words}) + 1.94$$

After finding the reading time, convert it into a reading distance by multiplying by the travel speed.

Step 2. Calculate the Decision Distance

The *decision distance* is the distance required to make a decision and initiate any maneuver, if one is necessary. After reading the sign, the driver needs this time to decide his/her course of action based upon the sign's message. Decision times range as follows:

- 1 s for simple maneuvers (e.g., stop, reduce speed, choose or reject a single destination from a D1-1 sign)
- 2.5 s or more for complex maneuvers (e.g., two choice points at a complex intersection)

After finding the decision time, convert it into the decision distance by multiplying by the travel speed.

Step 3. Calculate the Maneuver Distance

The *maneuver distance* is the distance required to complete the chosen maneuver. The maneuver distance depends on the course of action decided upon by the driver and the travel speed. The sign placement should consider all of the maneuvers that could be chosen based upon the message.

An example of required maneuver distances is provided in Table 22-8 for lane changes in preparation for a turn. These distances do not apply to situations in which drivers must stop. For high-volume roadways, more time may be needed to find a gap, while for low-volume roadways, some of the deceleration distance may overlap with the lane change distance.

Table 22-8. Maneuver distances required for preparatory lane changes.

Operating Speed (mi/h)	Gap-Search Distance (ft)	Lane Change Distance (ft)	Deceleration Distance (ft)
Non-Freeway Maneuver Distance Requirements			
25	66	139	77
35	92	195	154
45	119	251	257
55	145	306	385
Freeway Maneuver Distance Requirements			
55	218	306	308
65	257	362	462
70	277	390	549

Source: Pline (2001)

Step 4. Calculate the Information Presentation Distance

The *information presentation distance* is the total distance from the choice point (e.g., intersection) at which the driver needs information. This distance is calculated using the following formula:

$$\text{Information Presentation Distance} = \text{Reading Distance} + \text{Decision Distance} + \text{Maneuver Distance}$$

Step 5. Calculate the Legibility Distance

The *legibility distance* is the distance at which the sign must be legible. This distance is based upon the operating speed and the advance placement of the sign from the choice point. The legibility distance is calculated using the formula below:

$$\text{Legibility Distance} = \text{Information Presentation Distance} - \text{Advance Placement}$$

Step 6. Calculate the Minimum Letter Height

The *minimum letter height* is the height required for the letters on the sign based upon the legibility distance calculated above. It is also based upon the legibility index provided in the MUTCD (30 ft/in.).

$$\text{Minimum Letter Height (in.)} = \frac{\text{Legibility Distance (ft)}}{\text{Legibility Index (ft/in.)}}$$

Another consideration is the minimum symbol size. The minimum symbol size is based upon the legibility distance of the specific symbol that is being used. Table 22-9 contains daytime legibility distances for five types of symbols based upon research (Dewar et al., 1994).

From these legibility distances, we can obtain two general trends: (1) legibility distances vary by sign type and (2) legibility distances are greatly reduced for older drivers. Legibility distances for symbols are generally greater than for word messages.

Example Application

As an example, a driver approaches an intersection on a 35-mi/h (51 ft/s) roadway. The driver needs to read a simple designation sign (D1-1) that contains one destination word and

Table 22-9. Daytime legibility distances of five symbol types by age group.

Symbol Type	Number of Signs	Daytime Legibility Distances (ft)			
		Young	Middle-Aged	Old	Mean
Warning	37	736.4	714.7	581.5	677.6
School	2	573.3	634.7	501.2	569.7
Guide	21	472.3	461.5	366.0	433.3
Regulatory	12	464.4	437.9	367.4	423.1
Recreational	13	321.1	292.6	228.9	280.8

one symbolic arrow. The sign is placed 200 ft in advance of the intersection. The legibility index is assumed to be 30 ft/in. (FHWA, 2009). See Figure 22-9.

1. Reading Distance (ft) = $[(1 \text{ s/word})(1 \text{ word}) + (0.5 \text{ s/symbol})(1 \text{ symbol})](51 \text{ ft/s}) = 77 \text{ ft}$
2. Decision Distance (ft) = $(1 \text{ s/simple decision})(1 \text{ simple decision})(51 \text{ ft/s}) = 51 \text{ ft}$
3. Maneuver Distance (ft) = Gap Search + Lane Change + Deceleration = $92 \text{ ft} + 195 \text{ ft} + 154 \text{ ft} = 441 \text{ ft}$
4. Information Presentation Distance (ft) = Reading Distance + Decision Distance + Maneuver Distance = $77 \text{ ft} + 51 \text{ ft} + 441 \text{ ft} = 569 \text{ ft}$
5. Legibility Distance = Information Presentation Distance – Advance Placement = $569 \text{ ft} - 200 \text{ ft} = 369 \text{ ft}$
6. Letter Height = $(369 \text{ ft}) / (30 \text{ ft/in.}) = 12 \text{ in.}$ (when rounded to the nearest inch)

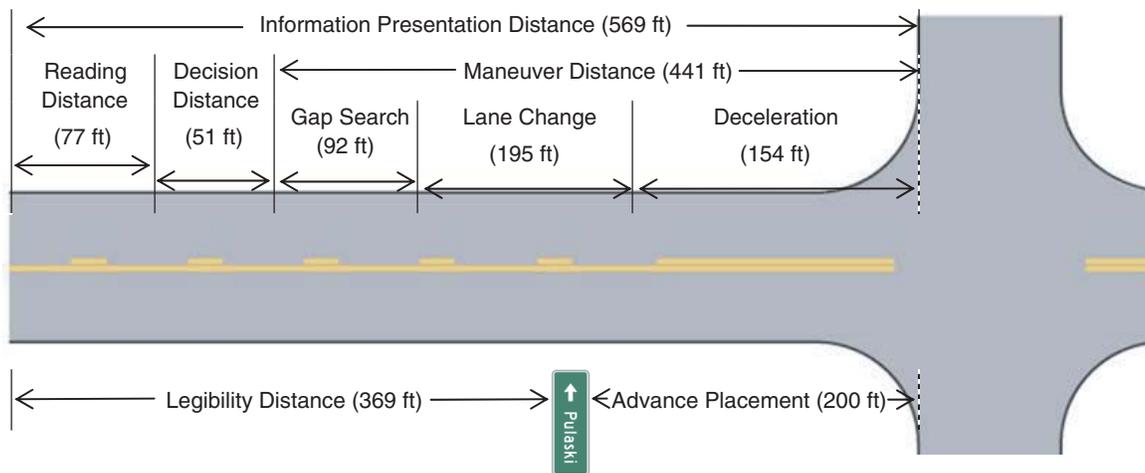


Figure 22-9. Graphic illustrating the example application of a driver approaching an intersection.

Tutorial 6: Calculating Appropriate CMS Message Length under Varying Conditions

The amount of information that can be displayed on a CMS is limited by the amount of time that the driver has to read the message. This amount of time in turn is determined by the legibility distance of the sign and the traveling speed of the passing vehicle. The *legibility distance* is the maximum distance at which a driver can first read a CMS message. According to Dudek (2004), this distance depends upon a number of factors including:

- Lighting conditions
- Sun position
- Vertical curvature of the roadway
- Horizontal curvature of the roadway
- Spot obstructions
- Rain or fog
- Trucks in the traffic stream

These obstructions and visibility limitations reduce the amount of time that the sign is within view or legible, ultimately requiring a reduction in the amount of information that is displayed on the CMS. The information that can be displayed is measured in information units. An information unit is a measure of the amount of information presented in terms of facts used to make a decision. For example, the location of the problem, the audience that is affected by the problem, and the recommended action to take are each 1 information unit. To determine the appropriate number of information units for display on a CMS, the following steps should be considered.

Step 1. Determine the Legibility Distance for the CMS

The maximum legibility distance for a CMS depends on the design characteristics of the sign (Dudek, 2004). These characteristics include the display type, character height, character width, character stroke width, and the font displayed. The base legibility distances found in Table 22-10 are presented in Dudek (2004) and are based on the results of several studies. The distances are based on all uppercase letters, 18 in. character heights, approximately 13 in. character widths, and approximately 2.5 in. stroke widths. Note that all of the information for light-emitting diode signs provided in this tutorial applies only to the newer aluminum indium gallium phosphide (or equivalent) LEDs.

Table 22-10. CMS legibility distances for varying lighting conditions.

Lighting	Legibility Distances (ft)			
	Light-Emitting Diode	Fiberoptic	Incandescent Bulb	Reflective Disk
Mid-Day	800	800	700	600
Washout	800	800	700	400
Backlight	600	500	400	250
Nighttime	600	600	600	250

Source: Dudek (2004)

Step 2. Use the Driver Speed to Find the Base Maximum Number of Information Units Allowed in a Message

The maximum number of information units is derived from the legibility distance of the CMS (which depends on the technology used) and the speed of the passing vehicles. The faster that the passing drivers are going, the less time they have to read the CMS message. Also, because the legibility distance of the sign depends upon the technology used, the number of information units also varies with the technology that is used. Finally, the diverse technologies perform differently under changing conditions. Table 22-11 presents the base maximum number of information units that can be presented for assorted CMS technologies, under several ambient lighting conditions.

Step 3. Adjust for Adverse Roadway and Environmental Conditions

There are many roadway and environmental conditions that reduce the visibility of CMSs and thus require a reduction in information units. Dudek (2004) provides further guidance on the exact number of information units that should be used under different conditions. The following sections describe how various conditions and factors lead to trade-offs in the number of information units that may be displayed.

Vertical Curves

The reduction in information units required for vertical curves depends on the design speed of the curve as well as the CMS offset from the road and mounting height. The following general relationships apply to CMSs on vertical curves:

- As the design speed of the curve decreases, the number of information units that may be used decreases.
- As the horizontal offset from the road increases, the number of information units that may be used decreases.
- As the mounting height of the CMS decreases, the number of information units that may be used decreases.

Table 22-11. Maximum number of information units per message for various technologies at different speeds.

Lighting	Maximum Information Units per Message											
	Light-Emitting Diode			Fiberoptic			Incandescent Bulb			Reflective Disk		
	0-35 mi/h	36-55 mi/h	56-70 mi/h	0-35 mi/h	36-55 mi/h	56-70 mi/h	0-35 mi/h	36-55 mi/h	56-70 mi/h	0-35 mi/h	36-55 mi/h	56-70 mi/h
Mid-Day	5	4	4	5	4	4	5	4	3	5	4	3
Washout	5	4	4	5	4	4	5	4	3	4	3	2
Backlight	4	4	3	4	3	2	4	3	2	2	1	1
Nighttime	4	4	3	4	4	3	4	3	3	3	2	1

Source: Dudek (2004)

In general, permanent CMSs that are mounted over the roadway are not affected by crest vertical curves (Dudek, 2004).

Horizontal Curves

The main concern with CMSs located on horizontal curves is the obstruction of the sign by roadside objects. Permanent CMSs that are mounted above or adjacent to the travel lanes will likely be high enough to be seen over any roadside obstructions. However, portable CMSs are usually closer to the ground and more likely to be obscured by obstructions. In general, the number of information units that may be used decreases when:

- The obstruction gets closer to the roadway
- The curve radius decreases (i.e., for tighter curves)

Rain

Rain does not generally affect CMSs (Dudek, 2004). However, when the intensity of the rainfall increases to 2 in./h or more, the visibility of the sign can be impacted. When the operating speed of the roadway is over 55 mi/h, Dudek (2004) recommends that the number of information units displayed on portable LED CMSs should be reduced by 1 information unit. Portable LED CMSs often use fewer pixels per character, and thus have lower luminance levels per character than permanent CMSs, which are relatively unaffected even in heavy rainfall. Therefore, signs utilizing other technologies should use fewer information units in heavy rainfall.

Fog

Fog can affect visibility even more than heavy rain. Generally, Dudek (2004) does not recommend a reduction in information units for permanent LED CMSs because of fog. A reduction is not necessary because of the high character luminance and contrast of permanent LED CMSs. However, portable LED CMSs require a reduction. The number of information units that may be used decreases when:

- The visibility range decreases
- The offset from the road increases

Trucks on the Roadway

Large trucks pose sight obstructions for other vehicles on the roadway. When a driver's view of a CMS is obscured by a truck, the driver has the option to change his/her traveling speed or position to see around the truck. However, as the number of trucks on the roadway increases, the amount of space that is available for drivers to do this repositioning decreases. Thus, the more trucks that are on the roadway, the more likely they are to impair the view of a CMS for other drivers.

Step 4. Adjust for Blanking Time

Greenhouse (2007) found that inserting a 300-ms blank screen between phase 1 and phase 2 of a portable message sign improves comprehension. The study is further discussed in the guideline

for *Displaying Messages with Dynamic Characteristics*. Although the blanking time was only tested between phases 1 and 2 (not between 2 and 1), it is reasonably conceivable that drivers who see a blank between phases 1 and 2, but not between phases 2 and 1, would reverse the order of the phases and possibly have trouble understanding the message. Dudek (1992) recommends that blank time and/or asterisks should be displayed between cycles of a message that contains three or more phases (on one-word or one-line signs). Because one-word and one-line signs are more limited in the amount of information that they can display at one time, the phases may not make sense independently and drivers who read later phases before phase 1 may not understand the message. Thus, giving an indication of where the message is in the cycle gives drivers an idea of their location in the cycle.

Overall, drivers may use the blanking time to determine where they are in the message cycle, even before the message is legible to them. There are additional benefits in terms of message comprehension as shown by Greenhouse (2007). However, the insertion of blanking time reduces the total available time for the driver to read the message, potentially requiring a reduction in information units. Thus, there is a trade-off between the benefits of providing blanking time and the number of information units that may be contained in the message.

Step 5. Display the Resulting Number of Information Units

After the calculations and adjustments from Steps 1 through 4 are performed, the result will be the number of information units that may be displayed in the message. If there are still more information units in the message than should be displayed, they should be reduced using the following steps, until the appropriate number of information units is reached (steps and examples adapted from Dudek (2004)).

Step 5A: Omit and Combine Information Units

First, attempt to reduce the number of information units without losing content by following the steps below.

- Omit unimportant words and phrases

Example:

<u>Original Message:</u>	<u>Shortened Message:</u>
ROAD CLOSED AHEAD	ROAD CLOSED
DUE TO CONSTRUCTION	1 MILE
FOLLOW DETOUR ROUTE	FOLLOW DETOUR

The word “Ahead” is unnecessary as drivers will assume the closure is ahead. The reason is less important than the location of the closure.

- Omit redundant information

Example:

<u>Original Message:</u>	<u>Shortened Message:</u>
MAJOR ACCIDENT	MAJOR ACCIDENT
ON I-276 NORTH	PAST I-80
PAST I-80	2 LEFT LANES CLOSED
2 LEFT LANES CLOSED	
KEEP RIGHT	

If the CMS is on I-276, the same freeway as the accident, the information is evident to the drivers and may be omitted. The information units “2 Left Lanes Closed” and “Keep Right” are redundant because drivers can assume that if the two left lanes are closed, they will need to move to the right.

- Combine base CMS elements

Example:

<u>Original Message:</u>	<u>Shortened Message:</u>
TRUCK ACCIDENT	FREEWAY CLOSED
PAST I-80	EXIT AT I-80
ALL LANES CLOSED	FOLLOW DETOUR
AT I-80	
I-287 NORTH TRAFFIC	
EXIT AT I-80	
FOLLOW DETOUR	

In the example above, the incident descriptor, incident location, and lanes closed message elements are combined into the information unit “Freeway Closed”. The location of the closure can be eliminated because the action element “Exit at I-80” describes the location.

Step 5B. Reduce the Number of Audiences in the Message

Example:

<u>Original Message:</u>	<u>Shortened Message:</u>
I-76 CLOSED	I-76 CLOSED
BEST ROUTE TO	BEST ROUTE TO
PHILADELPHIA/I-95	PHILADELPHIA
USE RTE-73 NORTH	USE RTE-73 NORTH

When using this reduction technique, message designers must use their judgment to decide which audience is more important to address in the message. In the previous example, the audience “Philadelphia/I-95” was reduced from 2 information units to 1 information unit, “Philadelphia”.

Step 5C. Use Priority Reduction Principles

If the message still contains more information units than should be displayed, the information units should be reduced in order of priority. The priority order is derived from the information drivers need the most in order to make driving decisions. In Table 22-12, the information units are listed in priority order, with number 1 being the highest priority information.

If the closure is due to roadwork, the effect on travel and good reason for following the action should be eliminated. Even though the incident/roadwork descriptor is useful to drivers, it may be replaced with the lanes closed element if necessary. When choosing information units to eliminate, the designer should start deleting units from the bottom of these priority lists first (i.e., element numbers 8 or 6). More examples of the application of these steps can be found in Dudek (2004).

Table 22-12. Order of priority for information units.

Lane Closures	Freeway/Expressway Closures
1. Incident Descriptor	1. Closure Descriptor
2. Incident Location	2. Location of Closure
3. Lanes Closed	3. Speed Reduction Action (if needed)
4. Speed Reduction Action (if needed)	4. Diversion Action
5. Diversion Action (if needed)	5. Audience for Action (if needed)
6. Audience for Action (if needed)	6. Effect on Travel (if needed)
7. Effect on Travel (if needed)	
8. Good Reason for Following Action (if needed)	

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*Covers Chapters 1 through 6, 10, 11, 13, 16 through 20, 22, and 24.

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Glossary

Acceptable Gap Distance—The size of the gaps in major-road traffic typically accepted by drivers turning from a minor road to provide sufficient time for the minor-road vehicle to accelerate from a stop and complete a turn without unduly interfering with major-road traffic operations.

Accessible Pedestrian Signals (APS)—Equipment for use at signalized intersections that communicates pedestrian signal timing information in non-visual formats. Features include push-button locator tone, tactile arrow, pushbutton information message, automatic volume adjustment, alert tone, actuation indicator, tactile map, Braille and raised print information, extended button press, passive pedestrian detection, and clearance interval tones.

AMBER Alert—An urgent broadcast regarding child abductions.

Apparent Radius—The curve radius as seen from the driver's perspective, which, in some cases, can make the curve appear distorted—either flatter or sharper—depending on topography and other road elements.

Appropriate Message Length—Sign message lengths that drivers have time to read and comprehend as they pass the sign.

Arcminute—One-sixtieth ($1/60$) of one degree (1°).

Arrow Panel Visibility—A roadway sign condition dependent on a number of factors, including the capability of the lamps in the panel, the type of roadway, the physical location of the panel, and the panel's relation to horizontal and vertical curves, ambient light, and weather.

Behavioral Framework for Speeding—Conceptual overview of the key factors relevant to speed selection, as well as their relationship to potential speeding countermeasures.

Bilingual Information—Information that is presented in more than one language on changeable message signs (CMSs).

Blank-out/Blanking—The period of time, or scheduled phase, when sign readouts are not being used.

Candela—The International System of Units (SI) base unit of luminous intensity.

Caution Mode Configuration—Arrow panel mode C, which provides flashing non-directional information to increase safety near highway work zones by providing early warning information to drivers indicating that caution is required while approaching and traveling through the work zone.

Changeable Message Sign (CMS)—CMSs are electronic, reconfigurable signs placed above or near the roadway and are used to inform motorists of specific conditions or situations. Also referred to as variable message signs (VMSs) or dynamic message signs (DMSs).

Clearance Interval—The period of time necessary for safe transitions in right-of-way (ROW) assignment between crossing or conflicting flows of traffic, including pedestrian activity; a combination of the yellow clearance interval plus the red clearance interval or an all-red interval.

Clearing Distance—The distance a vehicle travels beginning at the time the signal changes to yellow and ending at the time the signal changes to red.

- Closed-Loop Compensatory Component**—Part of the steering control process in which drivers continually monitor and adjust for deviations in position on the road based on feedback from near-field visual cues.
- Cognitive Preparation**—The various active mental activities that can influence response times and decisions of drivers and includes such things as driver expectancies, situational awareness, a general sense of caution, and where attention is being directed by the driver.
- Complexity**—A function or level describing how much information is being provided and how difficult it is to process.
- Complexity of Sign Information**—The number of information units being presented as part of roadway sign messages.
- Comprehension**—The combination of completing a task at hand, e.g., reading a sign, plus the process of making the resultant decision, e.g., right or left turn in response to the sign's information.
- Cone**—The portion of the roadway scene on the right-hand side of the roadway where a driver would typically look for road signs.
- Conspicuity**—The ease in seeing and locating a visual target, including signage, vehicles, bicycles, or pedestrians. In the context of road signs, it represents how easy it is to distinguish a sign from the surrounding visual environment.
- Crest Horizontal Curve**—A horizontal curve that also contains a vertical, concave down, component of curvature.
- Critical Gap**—For design purposes, the critical gap represents the gap between successive oncoming vehicles that average drivers will accept 50% of the time (and reject 50% of the time).
- Cross Section**—The width of the lane.
- Cross Slope**—The transversal slope of the roadway (described as a percentage) with respect to the horizon.
- Decibel (dB) Level**—A measurement that expresses the power or intensity magnitude of sound relative to a specified or implied *reference level*. A decibel is one-tenth of a bel, a seldom-used unit.
- Decision Sight Distance (DSD)**—DSD represents a longer sight distance than is usually necessary and is used for situations in which (1) drivers must make complex or instantaneous decisions, (2) information is difficult to perceive, or (3) unexpected or unusual maneuvers are required.
- Design Consistency**—Conformance of a highway's geometric and operational features with driver expectancy.
- Dilemma Zone**—The portion of the roadway formed between (1) the clearing distance to the intersection (the distance the vehicle travels between the time the signal changes to yellow to the time the signal changes to red) and (2) the stopping distance (the distance traveled by the vehicle between the times the signal changes to yellow to the time when the vehicle actually stops) when the stopping distance is greater than the clearing distance. The size of the dilemma zone is relative to the situation; it is not a fixed area.
- Drop-off**—Deterioration of roadways caused when the edges of the pavement become destabilized and eroded, resulting in a difference in height between the pavement surface and the roadside surface.
- Dynamic Characteristics**—Message properties that specify character movement such as time to display each message phase, to display blanking between phases of a multiphase message, and to flash one or more lines of a message.
- Dynamic Message Sign (DMS)**—DMSs are electronic, reconfigurable signs placed above or near the roadway and are used to inform motorists of specific conditions or situations. Also referred to as changeable message signs (CMSs) or variable message signs (VMSs).
- Effective Length of the Passing Lane**—The physical length of the passing lane plus the distance downstream to the point where traffic conditions return to a level similar to that immediately upstream of the passing lane.

- Effects of Roadway Factors on Speed**—The impact of geometric, environmental, and traffic factors on driving speed under free-flow conditions in tangent roadway sections.
- Empirical Bayes**—A method in which empirical data are used to estimate conditional probability distributions.
- Factors Affecting Acceptable Gap**—These factors are the driver, environment, and other situational factors—such as traffic volume, wait times, familiarity with the roadway or oncoming vehicle size—that cause most drivers or specific groups of drivers (e.g., older drivers) to accept smaller or larger gaps than they would otherwise accept under normal conditions.
- Fatal Accident Reporting System (FARS)**—National Center for Statistics and Analysis (NCSA) data system.
- Foveal Vision**—Central vision of the eye. The fovea, located in the pit of the retina, is the source of the eye's high visual acuity capability.
- Free-Flow Speed**—Free-flow speed is defined as conditions in which a driver has the ability to choose a speed of travel without undue influence from other traffic, conspicuous police presence, or environmental factors.
- Gap**—The time interval between two successive vehicles, measured from the rear of a lead vehicle to the front of the following vehicle, adapted from *Traffic Engineering Handbook* (Pline, 1999).
- Highway Systems**—The combination of three major components—the road (local roads, collectors, arterials and freeways), traffic control, and users with or without a vehicle.
- Horizontal Curves with Vertical Sag**—A horizontal curve that also contains a vertical, concave up, component.
- Human Factors**—A scientific discipline that tries to enhance the relationship between devices and systems and the people who are meant to use them through the application of extensive, well-documented, and fully appropriate behavioral data that describe and analyze the capabilities and limitations of human beings.
- Information Units**—A measure of the amount of information presented in terms of facts used to make a decision.
- Intersection Sight Distance (ISD)**—The stopping sight distance required at intersections. Actual ISDs will differ, depending on the type of intersection and maneuver involved.
- Lag**—The time interval from the point of the observer to the arrival of the front of the next approaching vehicle (Lerner et al., 1995, pp. 58–59).
- Lane Drop Markings**—Pavement markings that consist of short wide lines with short gaps used to delineate a lane that becomes a mandatory turn or exit lane.
- Legibility Distance**—The minimum distance at which a sign must become legible to a typical driver. It is calculated as a function of the time it takes a driver to read the sign, interpret the sign, and execute maneuvers that comply with the sign's message.
- Legibility Index**—The distance at which a given unit of letter height is readable.
- Long-Range Guidance**—Driving preview time for drivers of at least 5 s.
- Looming**—One of several dynamic characteristics of message signs, this term refers to increasing the size of text or symbols over time in a message display.
- Luminous Intensity**—A measure of the perceived power emitted by a light source in a particular direction per unit solid angle.
- Lux**—The International System of Units (SI) unit of illuminance and luminous emittance.
- Maneuver Time (MT)**—The amount of time required to safely complete a maneuver. MT is primarily affected by the physics of the situation, including vehicle performance capabilities, tire-pavement friction, road-surface conditions (e.g., ice), and downgrades, and to a lesser extent by driver-related factors (e.g., deceleration profile), although these factors are highly situation specific because the maneuvers encompass a broad range of actions (e.g., emergency stop, passing, left turn through traffic).
- Mental Models**—The system user's internal understanding and representation of an external reality.

- Most Meaningful Information (MMI)**—Information sought by drivers for particular road location and point in time through scanning the road environment in front of, behind, and to the sides of the vehicle they are driving.
- Open-Loop Anticipatory Control Process**—Part of the steering control process in which drivers predict road curvature and required steering angle based on far-field visual cues.
- Optic Flow**—The visual pattern caused by moving forward, in which points close to the point of expansion move outward slower than points more peripheral to it. This information is directly used by the driver's visual system to perceive motion.
- Passing Lane**—A lane added in one or both directions of travel on a two-lane, two-way highway to improve passing opportunities.
- Passing Sight Distance (PSD)**—The amount of distance ahead a driver must be able to see in order to complete a passing maneuver without cutting off the passed vehicle before meeting an opposing vehicle that appears during the maneuver.
- Pavement Drop-off**—Drop-offs are caused when the edges of pavement are destabilized and eroded, resulting in a difference in height between the pavement surface and the roadside surface.
- Perception-Reaction Time (PRT)**—The time a driver takes to process information, typically defined as the period from the time the object or condition requiring a response becomes visible in the driver's field of view to the moment of initiation of the vehicle maneuver. Per AASHTO (2004), bits of information on a scale from 0 to 6 bits is processed by the average driver at about 1 and 1.5 bits of information per second for unexpected and expected situations, respectively.
- Perceptual Requirements**—The visual information about the roadway and surrounding environment that drivers need to judge road curvature, determine lane position and heading, etc.
- Phase (for message signs)**—The text that is displayed at a single point in time on a message sign.
- Point of Expansion**—During forward motion, the point in the forward field that appears stationary relative to the observer (the observers' actual destination), and from which all other points are seen as moving away.
- Post-Mounted Delineators (PMDs)**—A type of marking device used to guide traffic; a series of retroreflective devices mounted above the roadway surface and along the side of the roadway to indicate the alignment of the roadway.
- Psychomotor Requirements**—The control actions (e.g., steering-wheel movements; foot movements to press brake, etc.) that drivers must make to maintain vehicle control or to facilitate other information acquisition activities.
- Raised Pavement Markers (RPM)**—A variety of three-dimensional devices used in conjunction with pavement markings to mark lane boundaries. They often have a reflective surface to increase visibility and produce a noticeable vibration or physical sensation when in contact with vehicle tires.
- Red Light Running**—Situations when drivers enter a signalized intersection when a red light is being presented.
- Retroreflective Raised Pavement Markers (RRPM)**—Raised pavement markers affixed to the road surface that are designed to reflect light directly back to the light source.
- Retroreflectivity**—The property allowing a surface to reflect a large portion of its light directly back to or near its source.
- Roadway Shoulder**—See Shoulder.
- Roundabout Intersection**—As defined by the MUTCD, roundabouts are circular intersections with yield control at entry, permitting a vehicle on the circulatory roadway to proceed, and deflecting the approaching vehicle counter-clockwise around a central island (FHWA, 2009).
- Safety Edge**—A wedge-shaped asphalt material placed between the roadway and the shoulder, which can be used as a drop-off countermeasure.
- Serial Processing**—A chain of events in which one step does not begin until the previous step is complete that is used to model some driver behavior.

- Shared-Use Lanes**—Roadways or lanes used concurrently by vehicles, bicyclists, or pedestrians in either rural or urban areas.
- Sharrows**—Shared-lane markings.
- Short-Range Guidance**—Preview time for drivers of up to 3 s.
- Shoulder or Roadway Shoulder**—A portion of the roadway contiguous with the traveled way for accommodation of stopped vehicles; for emergency use; and for lateral support of the sub-base, base, and surface courses. Also may be used by non-motorized traffic.
- Shoulder Drop-off**—A difference in height between the pavement surface and the roadside surface caused when the edges of pavement become destabilized and eroded.
- Shoulder Rumble Strips (SRSSs)**—A raised or grooved pattern on the shoulder of a travel lane to provide a tactile or audio alert to the driver.
- Sight Distance (SD)**—The distance that a vehicle travels before completing a maneuver in response to some roadway element, hazard, or condition that necessitates a change of speed and/or path. SD is based on (1) a perception-reaction time (PRT) required to initiate a maneuver (pre-maneuver phase) and (2) the time required to safely complete a maneuver (MT).
- Sight Distance at Left-Skewed Intersections**—The available sight distance to the driver's right side for a vehicle crossing a major road from a left-skewed minor road (where the acute angle is to the right of the vehicle).
- Sight Distance at Right-Skewed Intersections**—The available sight distance to the driver's left side for a vehicle crossing a major road from a right-skewed minor road (where the acute angle is to the left of the vehicle).
- Sign Comprehension**—The driver's or road user's ability to interpret the meaning of a sign. The ability to comprehend and use signs is associated with three stages: legibility, recognition, and interpretation.
- Sign comprehension can also consist of the sign reading task plus the process of making the resultant decision, e.g., right or left turn in response to the sign's information.
- Sign Design**—Design parameters of signs that impact the legibility of text placed on the sign, including retroreflectivity, legend color, font size, and font style.
- Sign Legend**—The text and/or symbols composing the message of a sign.
- Sign Legibility**—Specific design characteristics of signs that contribute to the drivers' ability to perceive and understand the sign's message.
- Sign Legibility Index**—An index created by the USSC to calculate sign letter height. To determine letter height divide the viewer reaction distance by the appropriate legibility index value (which varies depending on illumination, font style and case, as well as font color contrast to background).
- Sign Recognition**—The ability of the driver to readily distinguish the sign, especially in the context of other signs and stimuli.
- Speed Perception**—A driver's judgment of how fast he or she is traveling.
- Stopping Distance**—The distance traveled by a vehicle beginning from the time a traffic signal changes to yellow and ending at the time when the vehicle actually stops.
- Stopping Sight Distance (SSD)**—The distance from a stopping requirement (such as a hazard) that is required for a vehicle traveling at or near design speed to be able to stop before reaching that stopping requirement. SSD depends on (1) how long it takes for a driver to perceive and respond to the stopping requirement (PRT) and (2) how aggressively the driver decelerates (MT). This distance can be calculated as the sum of driver perception-reaction time + vehicle deceleration, under a range of visibility/traction conditions.
- Task Analysis**—Identification of basic activities performed by drivers as they navigate different driving scenarios by successively decomposing driving segments into tasks and subtasks/information processing elements.
- Title II of the Americans with Disabilities Act (ADA) of 1990**—Title II of the ADA is implemented in 28 CFR Part 35, which prohibits discrimination on the basis of disability by public

entities. *28 CFR 35.151 New construction and alterations* is available at <http://www.ed.gov/policy/rights/reg/ocr/edlite-28cfr35.html#S151>.

Traffic Engineering—The definition from ITE’s *Traffic Engineering Handbook* is “that branch of engineering which applies technology, science, and human factors to the planning, design, operations and management of roads, streets, bikeways, highways, their networks, terminals, and abutting lands” (Pline, 1999).

Viewer Reaction Distance—The distance a viewer will cover at a given rate of speed and reaction time, which can be calculated by speed of travel (ft/s) times perception-reaction time (s).

Visual Conspicuity—Characteristics of a sign that enable a driver to differentiate the sign from its surrounding environment.

Variable Message Sign (VMS)—VMSs are electronic, reconfigurable signs placed above or near the roadway and used to inform motorists of specific conditions or situations. Also referred to as changeable message signs (CMSs) or dynamic message signs (DMSs).

Work Zone Speed Limits—Reduced speed limits used in work zones to maintain safe traffic flow.

Yellow Timing Interval—Duration of the yellow signal indication (also referred to as the “yellow change interval” or “yellow clearance interval”).

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Abbreviations*

Δt	Sampling Interval
AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ABS	Anti-Lock Braking System
ADA	Americans with Disabilities Act
ADT	Average Daily Traffic
APS	Accessible Pedestrian Signals
ATIS	Advanced Traveler Information Systems
ASD	Available Sight Distance
cd	Candela
CIE	Commission Internationale de l'Eclairage
cm	Centimeter(s)
CMS	Changeable Message Signs
CVO	Commercial Vehicle Operations
dba	Sound intensity measured in decibels (relative to sound pressure level of 20 micropascals). The frequency spectrum is weighted to approximate human hearing.
DMS	Dynamic Message Sign
DSD	Decision Sight Distance
DVRE	Driver, Vehicle, Roadway, and Environment
EL	Edge Line
FARS	Fatal Accident Reporting System
FHWA	Federal Highway Administration
ft	Foot/Feet
g	Acceleration/deceleration equivalent to the rate of acceleration due to gravity. One g equals approximately 9.8 m/s ² .
HAR	Highway Advisory Radio
HCM	<i>Highway Capacity Manual</i>
HFG	<i>Human Factors Guidelines for Road Systems</i>
HSM	<i>Highway Safety Manual</i>
IA	Intersection Angle
IHSDM	Interactive Highway Safety Design Model
ISD	Intersection Sight Distance
ITE	Institute of Transportation Engineers
km/h	Kilometers per Hour
LD	Legibility Distance

*Covers Chapters 1 through 5, 10, 11, 13, 16 through 20, 22, and 24.

LED	Light-Emitting Diode
m	Meter
mcd	Millicandela
MH	Metal Halide
mi	Mile
mi/h	Miles per Hour
mm	Millimeter
MMI	Most Meaningful Information
MT	Maneuver Time
MUTCD	<i>Manual on Uniform Traffic Control Devices</i>
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NMSL	National Maximum Speed Limit
NTOR	No Turn on Red
PCC	Portland Cement Concrete
PMD	Post-Mounted Delineator
POV	Principal Other Vehicle
PRT	Perception-Reaction Time
PSD	Passing Sight Distance
R value	Correlation-coefficient
ROW	Right-of-Way
RRPM	Raised Reflective Pavement Marker
RT	Reaction Time
RTOR	Right Turn on Red
s or sec	Second(s)
SAE	Society of Automotive Engineers
SD	Sight Distance
SI	International System of Units
SLIDE	Simplified Location of Information Deficiencies
SR	Sampling Rate
SRS	Shoulder Rumble Strip
SSD	Stopping Sight Distance
SV	Subject Vehicle
SVROR	Single Vehicle Run off Road
TCD	Traffic Control Device
USSC	United States Sign Council
UVC	Uniform Vehicle Code
v/c Ratio	Volume-to-Capacity Ratio
VMS	Variable Message Sign
VPD	Vehicles per Day
vph	Vehicles per Hour
VSL	Variable Speed Limit
VTTI	Virginia Tech Transportation Institute

Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI-NA	Airports Council International-North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation