Sign Legibility and Conspicuity

DOUGLAS J. MACE
State College, Pennsylvania

> Back in the early days, in New England, they didn't have any tractors or big cranes. They used oxen. And when they got a great big log on the ground and they couldn't budge it, they did not grow a bigger ox—they used two oxen.
> Grace Hopper *(1)*

There are two perspectives from which to argue the importance of designing traffic signs to meet the needs of older drivers. The first, and perhaps more convincing, argument is contained in demographic data that document the growth in older age groups relative to other age groups. The second argument is derived from consideration of accident data and the overinvolvement of older drivers in accidents and fatalities. Both lead to the conclusion stated by Staplin *(2)* in a review of age-related diminished capabilities that "it is prudent to anticipate ways in which the present system of traffic control devices may fail to accommodate the special needs of this group of motorists."

Demographic projections for the older population are presented by Rosenbloom elsewhere in this volume. A review of these projections and their associated data leads to several unambiguous conclusions. However one defines older drivers, their representation in the driving population is rapidly increasing. Also, the older population varies in physical abilities and their use of motor vehicles. The classification of older people by Neugarten *(3)* into the young-old and old-old is most useful. The over-75, or old-old, group is growing faster than any other *(4)*. However, the young-old group is more dependent than the old-old group on personal use of motor vehicles, and it is their needs that are addressed in this paper.

It has been observed that the rapidly expanding mobility of older drivers has not brought about responsive change in the interrelated vehicle-highway-driver system *(5)*. This transportation system is of fundamental importance to the life-style of older persons in the United States, just as it is for all other Americans. It is therefore logical to attend to all components of automobile travel if the mobility and safety of older persons is to be improved. These components include vehicle design, driver education, and highway construction and maintenance.

To downplay the problem, it is sometimes suggested that older drivers take compensatory actions that improve safety. First, the nature of their trips changes, particularly after retirement, so that much of their travel is during daylight and off-peak hours *(6)*. Retirement, however, encourages vacation travel and driving in unfamiliar surroundings, which increase the dependency of older drivers on signs. Also, older persons drive more slowly and tend to stay in the right lane on multilane highways. Although it is true that driving is often regarded as a self-paced task, this style of driving may itself be hazardous in the heavy volume of daytime urban travel.

The demographic changes already discussed suggest that many more dramatic changes in the life-style and highway use of older drivers may be forthcoming. As life span increases and older people become a larger percentage of the total population, pressures may arise to force retirement to occur later in life, changing current driving patterns. It is easier to imagine people working while in their seventies than to imagine that worker productivity can be increased to support the social cost of a rapidly increasing retirement group.

Although elderly drivers are known to be overrepresented in traffic fatalities, the reasons behind this are far from certain *(7, 8)*. Attempts to relate driver performance (measured by either accidents or violations) to age-related impairments or signing deficiencies do not suggest any single obvious course of remediation.

Maleck and Hummer *(8)* observed that in rural settings older drivers are less likely to be the cause of accidents. Staplin *(2)* observed that the principal problems of older drivers, as measured by accidents and violations, appear to involve left turns, yields, and merges. Harrington and McBride *(9)*, comparing violation rates on a mileage basis, noted that older drivers are most likely to fail to yield right-of-way and to disobey traffic signs.

Although visibility of existing signs may contribute to these documented driving errors, there may be other contributing causes: cognitive processing problems, missing signs, and unclear and confusing information. A recent survey by Yee *(10)* found that 25 percent of elderly drivers experienced problems reading traffic signs. Of these, the most frequently reported problem (42 percent) was sign placement. Other problems, reported equally often, were size, clarity of lettering, and clarity of message. In addition, difficulty with signs occurred more often in or around cities.

The focus of this paper is on improving the highway transportation system for older drivers through the maintenance of adequate sign legibility and conspicuity. The need for standards is suggested by reports of increasing costs arising from tort liability cases. Signing deficiencies were cited as the primary factor in 20 percent of sampled tort actions *(11)*, second only to pavement deformities (22 percent). When only those accidents involving a fatality or serious injury are considered, signing deficiency is the primary factor.

The overrepresentation of nighttime accidents has been the basis of arguments to implement standards to maintain sign reflectivity at necessary levels. The tendency of older drivers to drive less at night is somewhat negated by the exposure-adjusted nighttime accident rate of older drivers coupled with the demographic and life-style changes already mentioned. These factors argue for consideration of both daytime and nighttime conspicuity and legibility.

Mace et al. *(12)* developed an analytic framework for evaluating the adequacy of any sign. The framework reflects the principles of supply and demand and is based on the simple observation that drivers demand a minimum time and therefore distance to process and respond to information and that the characteristics of signs, headlamps, and the highway determine how much distance and therefore time are supplied to the driver. This discussion will cover driver requirements (i.e., demand for conspicuity and legibility) and how they are affected by driver age, supply of conspicuity and legibility under current design practice, and alternative methods of implementing conspicuity and legibility requirements.

REQUIREMENTS OF OLDER DRIVERS

Research has shown that drivers require a minimum amount of luminance contrast for both conspicuity and legibility. Signs must first be detected (sometimes on a visually complex background) and then the information must be processed and understood. This should all happen before a sign has been passed, and sometimes (e.g., at a Stop sign) with enough distance remaining to permit a vehicle manuever (e.g., deceleration to a stop) before the sign has been reached.

Although it cannot be proved that insufficient sign legibility and conspicuity contribute to the driving problems of older drivers, the verbal reports in studies such as that by Yee *(10)*, the role of signing in accidents, and the involvement of older drivers in accidents suggest that it does. More basic is the fact that both analytical and empirical studies show increasing luminance thresholds for sign legibility and conspicuity with age.

It is important, however, to recognize that one cannot discuss a visual requirement applicable to all signs. Mace et al. *(12)* discussed the influence of factors such as motivation, uncertainty, use of symbols and purpose of sign message, and so forth, on conspicuity and legibility requirements. Because these factors are affected by age, it is important that they be considered in determining the specific requirements of older drivers.

Information Distance

Safe driving is heavily dependent on control, guidance, and navigation subtasks, as discussed by Alexander and Lunenfeld *(13)*. Guidance and navigation require having the time necessary to process information and execute an appropriate response. The basic visibility requirement model for signs is based on the Decision Sight Distance (DSD) model presented by McGee et al. *(14)*. In this model it is assumed that the driver needs time to detect a sign, comprehend its message, make a decision, initiate a response, and implement or complete a vehicle manuever before reaching the sign.

When the DSD was automated, Mace *(12)* built a Sign Dictionary that classifies all signs in the *Manual on Uniform Traffic Control Devices* (MUTCD) on the basis of components of the model that are relevant to that sign. Depending on which components are necessary, the model (assuming serial processing) combines the time estimates and applies the estimated time to the operational speed to compute the DSD.

The model, now the Minimum Required Visibility Distance (MRVD) model *(15)*, is being revised under a current FHWA contract to account for differences resulting from driver age. The MRVD for older drivers can be considerably longer than that for younger drivers because of diminished cognitive abilities and changes in motivation and risk-taking behaviors. Signs that require most or all of the DSD components will therefore potentially be more affected by driver age than those that only need to be detected and read. MRVD is a reasonable model for estimating legibility and detection distance requirements of signs in general.

Without reference to MRVD one might think that the special needs of older drivers for conspicuity and legibility are based solely on visual impairment. The concept of MRVD makes it obvious that factors such as reaction time, decision making, and problem solving increase the distance needed by the older driver to detect and read signs, and that these factors can create visibility problems for the older driver even when visual impairment is not added. In general, older drivers not only have problems seeing what younger drivers can see at a given distance but also need to recognize and be able to read signs at greater distances to provide them with the additional time needed to respond in a safe manner.

Age-Related Impairment

It is well known that age is associated with diminished capacities in sensory-perceptual, cognitive, and psychomotor skills that are all related to safe driving performance. Less clear, perhaps, is which diminished capabilities make a difference. Several reviews (*2*; *16*, pp. 131–159; *17*, pp. 121–130) substantiate that as people age, visual acuity and contrast sensitivity decline, the visual field contracts, and depth perception diminishes. As a result, older drivers experience a decline in peripheral vision, glare resistance, glare recovery, and the ability to focus. Lindholm et al. *(18)* report a number of basic research studies on the effects of aging on perceptual and cognitive processes and generalize to the highway environment. Their principal findings relate to the interaction between sign attributes and task characteristics and the increased processing time required by older drivers. Milone *(19)* summarizes cognitive changes as follows:

> While long-term memory loss and learning skills seem not to deteriorate, a decline in short-term memory causes problems, especially in organizing information coming from a variety of sources. Decision-making in traffic is less acute. There is some decline in the ability to estimate the passage of time and to judge the speed of other motor vehicles. The traffic environment may produce too many cues at one time, thus causing confusion or erratic driving behavior.

Yanik has conducted a literature review on the effects of aging *(20)* and reached the conclusion that the aging process does affect a driver's ability to perceive and process information from road signs. He observes that older drivers need large sign messages with high contrast, that they would be expected to take more time to find signs in cluttered backgrounds, and that they take longer to respond.

It is most difficult to make predictions about driving performance from tests of driver impairment, whether in the laboratory or in the field. The relative importance of this impairment under actual driving conditions will vary enormously depending on driving conditions, which include volume, road geometries, weather, and complexity of the visual field. Signing alternatives that do not produce significant effects in a research study may do so when observed under the higher demands of city driving. Alternatives that produce significant performance differences in the laboratory may not be meaningful in terms of real-world driving, which can be, depending on the situation, a self-paced task. This may explain the difficulty in identifying valid predictors of driving performance.

As mentioned earlier, decrements in cognitive and psychomotor functions may increase the time required by the elderly driver and therefore the distance at which the sign must be legible. Decrements in sensory and visual performance will change the level of visual thresholds and may also increase the time and distance requirements for processing traffic signs.

Effects of Age on MRVD

To determine the effect on visual requirements of increases in required detection and legibility distance, it is necessary to examine the effects of impairment on the perception-reaction time (PRT) component of the MRVD model. Research shows that older drivers spend more time looking at irrelevant stimuli, which suggests that a longer time for the detection component of MRVD may be necessary. Although older drivers do not appear to require more time to read sign messages *(2)*, additional time for recognition may be necessary for specific signs whose message is not clear. Studies of symbol recognition suggest that clear graphic symbols may decrease the recognition-time component of MRVD *(21)* and reduce recognition distance as well *(22)*.

Decision time is the component of MRVD most likely to show differential age effects. Staplin reviewed several studies that show age-related decrements in tasks associated with higher-order cognitive processing. He concluded that "as decision making becomes more complex and problem solving requires more steps, speed and efficiency are diminished in older adults." Older drivers need more information and take more time to select an appropriate response. Decision time is often site specific: the characteristics of the sign location often increase the level of complexity. This may explain the problems of older drivers at some intersections.

Simple reaction time and brake reaction time increase with age, but the increase is a modest 10 percent, or about 50 msec *(18)*. Olson and Sivak *(23)* came to the same conclusion based on the PRT data mentioned earlier. A recent study *(6)* supports this finding, indicating that when tasks are more complex, imposing greater cognitive demand, the older person's reaction time increases by more than 30 percent.

Sign Conspicuity

The issue of sign conspicuity has been addressed by several authors. Cole and Jenkins *(24)* operationally define a conspicuous object as one that will, for a given background, be seen with certainty (greater than 90 percent probability of detection) within a short observation time (250 msec) regardless of its location in the visual field. Mace et al. *(12)* have suggested that driver motivation and expectancy should also be considered in any definition of a conspicuous object. This distinction allows for manipulation of conspicuity by changing the driver's "set" so that changes in a sign or its location are not always necessary. Guide signs are more conspicuous to drivers looking for them (i.e., motivated) and Stop signs following a Stop Ahead sign are more conspicuous to everyone (i.e., there is high expectancy). Conspicuity may therefore be aided by multiple or advance signing as well as changes in size, luminance, and placement of signs.

Criterion

To satisfy the need for conspicuity, detection should not be confused with threshold size or brightness. The criterion for the study of visual thresholds is frequently set at 50 percent accuracy, far too low for traffic sign conspicuity. Also, in the experimental paradigm observers usually know what the target is and either when or where it will appear. Threshold luminance for detection under these circumstances is far below that required for traffic sign conspicuity. Less than 0.1 candela (cd)/ft^2 is required for detection of a 30-in. traffic sign at a distance of 1,740 ft where the visual angle subtended is about 5 arc min. Threshold detection for typical traffic signs is over 3,000 ft (25). Although detectable, signs at this distance are not conspicuous objects.

Visual Complexity of Highway Scenes

The role of visual complexity in the conspicuity of traffic signs has been studied in nighttime scenes by Mace *(26, 27)* and in the daytime by Jenkins *(28)*. Both studies found scene complexity to be a significant determinant in sign detection. In general, rural scenes may be thought of as low in complexity and urban scenes as high in complexity; however, the reports of both Mace and Jenkins show that scene complexity is not undimensional and that simple measures such as visual clutter are poor predictors of detection performance. Specifically, complex nighttime scenes are those that place high demands on driving (e.g., multiple lanes, other traffic, signals) and in which there is a significant amount of reflective or light sources in the area searched for signs *(26)*. Similar measures are not available for daytime complexity. It is reasonable to hypothesize that visual complexity would have a significant effect on older drivers because they are more likely to be distracted by irrelevant stimuli *(2)*. Evidence that an age effect does not exist when visual search is not required suggests that advance warning and sign placement may be very effective in improving sign conspicuity for older drivers.

Size and Luminance

Data do not exist from which to prepare a set of contrast modulation curves for sign conspicuity. What is known about conspicuity suggests that separate curves would be required for levels of visual complexity, target eccentricity, and driver attention and uncertainty. Cole and Jenkins *(24, 29)* determined that during daylight, size and visual complexity of the scene are more important determinants of conspicuity than target brightness. Many authors have shown the importance of contrast to sign conspicuity, but the effect of contrast diminishes at high levels of visual complexity *(26)*.

Under real-world driving conditions a shoulder-mounted 30-in. yellow diamond was recognized at distances ranging from 600 ft (14 arc min) to

1,400 ft (6 arc min), depending on its luminance and the visual complexity of the surround *(26)*. Signs measuring 1.5 cd/m^2 provided detection distances greater than 500 ft for 30-in. signs when visual complexity was low. When visual complexity was high, signs with luminance of 0.3 cd/m^2 were inadequate to provide 500-ft detection distances.

Other Factors

The alertness of the driver and his degree of knowledge about what he is looking for and where are also primary determinants of conspicuity *(12)*. This hypothesis is supported by others. Roper and Howard found that detection distances for darkly clothed pedestrians averaged 50 percent less when drivers were not alerted *(30)*. A similar difference was observed in PRT by Olson and Sivak *(23)* when data from a reaction to an unexpected obstacle were compared with reaction to a brake light when there was no uncertainty about what and where the target would be. The effect of alertness and lack of surprise will be larger for targets not on the road, which require peripheral vision to be conspicuous. Eccentricity has not been researched for the unalerted, low-certainty condition. How these variables might interact with age also needs to be studied. Differences in glare sensitivity, restricted peripheral vision, and the process of selective attention may cause higher conspicuity thresholds for older drivers.

The use of color on highway signs has been studied both as an aid in conveying information and as an aid in detection. Although the MUTCD provides that green be used for guidance, red for prohibition, and so on, a study of the ability of the color code to convey information produced generally negative results *(31)*. Studies of color as an aid to conspicuity have been inconclusive. At least two studies *(32, 33)* have suggested that color has potential as an aid in detection, but Jenkins and Cole *(34)* provide conflicting data. The discrepancies are likely to be the result of differences in the experimental task, but may also be due to differences in background that would limit the generalizability of color as a useful code. Color is obviously not a requirement for conspicuity, but its role as an aid in detection, particularly for older drivers, needs further study.

Legibility

Legibility has been more heavily researched than any other factor related to signing. The primary variables affecting legibility are letter height, stroke width, letter width, spacing, direction of contrast, amount of contrast or reflectorization, and surround brightness. The principal methods used to improve legibility are increasing sign size (which may be used to increase letter height) and increasing reflectance (which may be used to change contrast or increase luminance). Changes in stroke width (for nighttime legibility) and modest changes in color saturation or lightness (for daytime legibility) may also be used to the extent allowed by the MUTCD requirements for standardization.

Sivak and Olson *(35)* and Mace et al. *(12)* have reviewed much of the research on sign legibility and have drawn attention to the variability in recommended luminance levels. Research on luminance requirements of traffic signs has focused on establishing both minimum and optimum levels for legibility. When a sign is fully reflectorized, the luminance requirements are described in terms of both brightness and contrast of the brightest component (typically the letters) against the background. Signs with only one reflectorized component are measured with respect to luminance of the reflectorized material.

Effects of Aging on Luminance

The validity of high-luminance static visual acuity as the primary vision standard for driver licensing is discussed elsewhere in this volume. Whatever the validity of static acuity for measuring driver safety, recent studies show static acuity to be a poor predictor of nighttime legibility. When older and younger drivers were matched on high-luminance acuity, older drivers were found to perform substantially more poorly than younger drivers *(36)*. This finding was verified by Sivak et al. *(37)*. These authors also found low-luminance static acuity to be uncorrelated with detection distance, leaving unresolved the question of what causes the underperformance of older drivers.

Evans and Ginsburg *(38)* report studies that demonstrate Snellan acuity to be a poor real-world predictor of vision performance. Research by these authors has shown that an individual's ability to identify a target of one size under one contrast condition does not predict performance with another size of target under a different contrast condition. The hypothesis that contrast sensitivity measurements can be used to predict age-related differences in the legibility of traffic signs was supported. Again, no significant relationship existed between Snellen acuity and discrimination distance.

With regard to the effect of aging on legibility, the following generalizations were noted by Olson et al. *(39)*:

- Older drivers require more contrast between the message and the background of a sign than younger drivers to achieve the same level of performance.
- Legibility losses with age are greater at low levels of background luminance. A reduction in legibility distance of 10 to 20 percent should be assumed when signs are not fully reflectorized.

• Signs are more likely to suffer a loss in legibility for older drivers when luminance is increased beyond the optimum level on a partially reflectorized sign.

• Surround luminance improved the legibility of signs more for older drivers and reduced the negative effects of excessive contrast.

Optimum Luminance

Sivak and Olson *(40)* provide optimum and replacement values for partially reflectorized signs on dark surrounds on the basis of their literature review. Legibility is generally an inverted U-shaped function similar to those shown in Figure 1. The optimum value is the crest of a curve such as those shown in Figure 1. The problem is that a large number of curves exist for different colors, surround luminance, driver age, and, for fully reflectorized signs, background luminance. The crest forms at different locations and sometimes not at all.

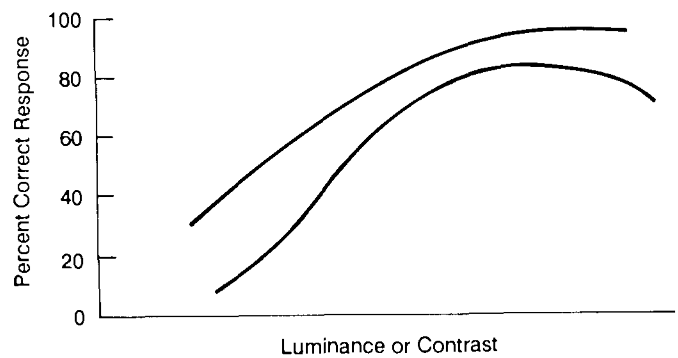

FIGURE 1 Generalized legibility function.

The optimum value of 75 cd/m^2 provided by Sivak and Olson is the geometric mean of six studies with recommendations ranging from 24 to 343 cd/m^2. For fully reflectorized signs they recommend a contrast ratio of 12:1. For example, if the luminance of the green background was 5 cd/m^2, the luminance of the legend should be 60 cd/m^2. The optimum value is primarily relevant to the goal of increasing sign brightness to enhance conspicuity.

Unless conspicuity is of primary concern, brightness and contrast should be kept below their optimum values to ensure that legibility is not sacrificed. Excessive contrast (or luminance on partially reflectorized signs) is more likely to degrade legibility for older drivers *(39)*. In the following section on luminance supply, it is shown that available materials are unlikely to reach 75 cd/m^2. However, several studies suggest lower optimal values for some situations. Highly reflective materials, particularly prismatic button copy, could provide a legibility problem, but they are typically used on fully reflectorized signs where contrast is kept below optimum levels. On dark roads, signs above the optimal luminance are thought to have poor legibility because of irradiation. However, in brightly lit areas, where conspicuity may be a problem, research by Allen *(40)* indicates that highly reflective signs should not create a legibility problem.

Minimum Luminance

Establishing minimum or replacement luminance standards requires an estimate of driver requirements. Unfortunately, a consensus does not exist with regard to minimum requirements. Forbes and Holmes *(41)* used a legibility index (distance in feet at which a letter is legible per inch of letter height) to describe the relative legibility of different letter styles (ratio of height to stroke width). Under daytime conditions, Series B, C, and D letters were reported to have indexes of 33, 42.5, and 50. Forbes et al. *(42)* found Series E letters, which are wider than Series D, to have an index of 55. Over time the value of 50 ft per inch of letter height has become a nominative, though arbitrary and disputed, requirement. The most valid estimate of legibility requirements for traffic signs is the MRVD. Either letter size or legibility index may be manipulated to satisfy this basic distance requirement. Therefore the following relationships should be noted:

Required letter size = MRVD / legibility index

or

Required legibility index = MRVD / letter size

From the standpoint of sign maintenance management, luminance and contrast cannot be expected to compensate for inadequate size. Therefore, it is important that the required size be determined at the time of installation.

The minimum luminance for traffic sign replacement should provide the required legibility index, given a letter size and MRVD. Sivak and Olson *(35)* provide an estimate of 2.4 cd/m^2 (0.22 cd/ft^2) for the 50th-percentile legibility requirement on the basis of their literature review. This estimate represents ideal conditions and requires adjustment for the effects of age, misalignment, glare, and so forth. However, 2.4 cd/m^2 is not adequate for conspicuity at high levels of background complexity *(26)*, and it is questionable that it is representative of the needs of older drivers.

At low levels of background luminance, legibility is determined by the luminance of the message alone. As luminance of the background increases, the required amount of contrast between message and background decreases. In general, a contrast range of 4:1 to 15:1 is appropriate for most conditions. Lower contrast is not acceptable, and contrast as high as 50:1 is typically not a problem. Like conspicuity, the luminance requirements for traffic signs vary with the brightness of the surround. Older drivers require more luminance from partially reflective signs and more contrast from fully reflective signs than younger drivers to achieve the same level of performance.

Olson and Bernstein *(36)* suggest that older drivers should not be expected to achieve a legibility index of 6 m/cm under most nighttime circumstances and that even 4.8 m/cm should be expected only with fully reflectorized signs. The data provided by Olson et al. *(39)* give some expectation that 4.8 m/cm is a reasonable goal under most conditions. Their data compare young and old drivers on luminance and contrast requirements for different legibility criteria, different colors, background, and surround luminance. A 4.8-m/cm standard can generally be achieved by older drivers with contrast ratios greater than 5:1 (slightly higher for guide signs) and luminance greater than 10 cd/m^2 for partially reflectorized signs.

CURRENT DESIGN PRACTICE

The standards relative to the visibility of traffic signs are those that determine sign design (including color, shape, legend, stroke width, etc.) as well as sign size and brightness. Size and brightness are the dimensions generally considered in attempts to improve sign visibility because the other dimensions are more strictly controlled by the MUTCD. In practice, size is established by the MUTCD and adjusted in response to level of service and design speed, not MRVD requirements. Because color is the major determinant of daytime internal sign contrast, daytime legibility is primarily manipulated by size. For a specified color, nighttime contrast is determined by the reflectivity of the material chosen.

The federal standards for luminance of retroreflective materials are acceptance standards defined in terms of specific intensity per unit area (SIA) and provide no differentiation based on driver need. Standard FP-85 provides minimum values of SIA for materials made from different manufactured processes, for example, Type II enclosed lens engineering grade and Type III encapsulated high-intensity sheeting.

Requirements are specified for two observation angles (0.2 and 0.5 degree) and two entrance angles (–4 and 30 degrees). The observation angle is that between the light beam going from headlamp to sign and the reflected light beam seen by the driver, in other words, the line of sight. The entrance angle is that between the light beam striking the sign surface and a perpendicular line coming straight from the surface. The specifications for different observation and entrance angles are necessitated by the decrease in sign reflectivity as these angles increase and the general increase as a vehicle approaches a sign. The specifications attempt to guarantee minimum performance at short distances.

The MUTCD specifies simply that all warning and regulatory signs be reflectorized or illuminated to show the same color and shape by day and night unless specifically excepted in the standards. There are no minimum initial or replacement standards for retroreflective signs. New signs are installed with reflectivity depending on the material chosen. This choice and guidelines for replacement are left to practices that vary between the states and levels of government.

The federal standards suffer from three major inadequacies. First, as noted earlier, they are acceptance standards and do not guarantee that the sign, as used, will meet user requirements when new. The MRVDs of different signs (or the same sign in different locations) are dramatically different and therefore the range of relevant observation and entrance angles is not the same for every sign. Critical detail is different and therefore luminance and contrast requirements differ.

Second, the standards address the issue of accelerated wear as another acceptance test, and do not address the more critical issue of when a sign ceases to perform its intended function.

Finally, the standards apply only to the materials from which signs are made and not to the sign fabrication process or sign placement.

Many signs [approximately 80 percent of those of the Pennsylvania Department of Transportation (PennDot)] are made using a reverse-screen process. The federal standard for red sheeting, for example, does not apply to the performance of Stop signs or any other red sign when the red is silk-screened onto a white sheeting. The luminance of the message may be controlled by the standard for white sheeting, but the contrast of a sign made by the reverse-screen process is not determined by the federal standards.

PennDOT has established standards for their reverse-screen colors that are generally lower than the federal standards for the same colors of the same material. The contrast ratio for signs with a reverse-screen process is higher than that for cutout letters on a colored sheeting. Adding to the confusion is the existence of some state standards. PennDOT's standard for federal Type II material is about 30 percent higher for white; the same is true for other colors. Differences among the standards for various colors and other materials are not so predictable. Some values are higher in Standard FP-85; others are higher in PennDOT standards. Some differ only at some observation or entrance angles.

Table 1 compares contrast ratios available using FP-85 standards and those provided by PennDOT standards for three types of retroreflective material.

TABLE 1 CONTRAST RATIOS OF FULLY REFLECTORIZED SIGNS

	White on Red	White on Green	White on Blue
FP-85 Standards			
Type II	5	8	17
Type IIa	5	5	14
Type IIIa	6	6	13
PennDOT Standards			
Type II	11[a]	10	NA
Type IIa	5[a]	5	16[a]
Type III	8[a]	6	12

[a]Reverse-screen standard.

The most notable differences are that PennDOT standards achieve higher contrast ratios with Type II sheeting (because of their higher specification for the reflectivity of white), and a higher contrast ratio for white-on-red Type III sheeting (because the reflectance of a reverse-screen red is about 70 percent that of red sheeting).

IMPLEMENTATION OF CONSPICUITY AND LEGIBILITY REQUIREMENTS

To provide a basis for substantive improvements in sign design and replacement strategies, problems found in current design practice will be examined. As mentioned earlier, the comparison of supply and demand provides a convenient paradigm for conducting this analysis. The problems created by inadequate supply of luminance may be rectified by increasing luminance or contrast or by decreasing the demand for luminance, that is, increasing sign size or reducing MRVD. If the information needs of older drivers are to be addressed, both techniques must be openly considered.

Optimum and Replacement Luminance

Recommendations for sign standards should not make it necessary to have complex sign inventories. It is reasonable to require several sign sizes and to stock signs of different materials. However, it is not reasonable to stock different materials made into all the possible sizes of the same sign. Management decisions made to simplify inventory should err on the side of safety and provide more size and reflectance than may be needed.

As mentioned earlier, care should be taken to install signs of adequate size so that daytime performance is maintained and luminance requirements are kept realistic. If signs are to provide adequate visibility for older drivers, the size of Series D and E letters should be based on an assumed legibility of 40 ft/in. (4.8 m/cm) of letter height and not 50 ft/in. (6.0 m/cm) *(36, 39)*. For example, if the MRVD is 600 ft, the minimum letter size should be 15 in., not 12 in. At distances of 300 ft, 8-in. letters should be used in place of 6-in. letters to accommodate older drivers.

With regard to legibility of fully reflectorized signs, any of the materials reviewed earlier provide adequate contrast when new, assuming a criterion of 40 ft/in. of letter height. Materials should be chosen on the basis of cost, durability, and need for conspicuity. Sign maintenance practice should provide more frequent inspection of signs with 5:1 ratios to be certain that they do not deteriorate to unacceptable contrast levels.

Determining which materials provide adequate luminance for legibility on partially reflectorized signs is more difficult. For a given required luminance, the required retroreflectance varies with sign distance and placement. Sivak and Olson provide a table that can be used to determine the retroreflectance needed to provide a specified luminance at 600 ft for right, left, and overhead placement. Table 2 gives the estimated coefficients of retroreflection (also referred to as SIA) for Sivak and Olson's suggested optimum luminance (75 cd/m^2) their 50th-percentile requirement (2.4 cd/m^2) as well as the author's more conservative estimate of 10 cd/m^2. To allow for a 25 percent deterioration factor, new signs should have at least 33 percent more reflectance than the minimum values indicated.

TABLE 2 COEFFICIENTS OF RETROREFLECTION USING U.S. TYPE LOW-BEAM HEADLAMPS

	Luminance (cd/m^2)		
Sign Placement	2.4	10.0	75
Left shoulder	90[a]	360	2,806
Overhead	114[a]	460	3,547
Right shoulder	24[a]	100[a]	736

NOTE: 1 cd = 10.76 lx.

[a]May be satisfied by reflective sheeting.

Table 2, applicable to signs requiring 40 ft/in. of legibility at distances of 600 ft (e.g., guide signs), suggests that only the requirements of the 50th-percentile (2.4 cd/m^2) right-shoulder signs can be satisfied by retroreflective sheeting. The data in Table 2 imply that to be legible by older drivers all other signs requiring a minimal luminance of 10 cd/m^2 and a legibility distance of 600 ft should have button copy or should be fully reflectorized.

Most regulatory and warning signs do not require a 600-ft legibility distance and many do not require 40 ft/in. of legibility. It is quite possible that retroreflective sheeting can meet the requirements of older drivers in many situations. Relevant data should be forthcoming from a current FHWA study. Mace *(12)* found that the 2.4-cd/m² estimate corresponded very well with the subjective evaluation of signs requiring replacement by those experienced in traffic signing, but whether these meet the needs of older drivers must still be determined.

One reason why many of these signs may function well with retroreflective sheeting is that the critical detail of signs with symbols (or those whose shape conveys adequate information) subtends an excess of visual angle so that they do not require 40 ft/in. of legibility. These same signs often have simple messages with short PRTs, which reduces the MRVD.

A short MRVD, however, does not necessarily produce a more legible sign. As a vehicle approaches a sign the luminance increases because more illumination from each headlamp reaches the sign (i.e., the inverse-square law); however, as the entrance angle widens, luminance decreases because of the performance of the retroreflective sheeting and headlamp aiming. The result is that sign brightness typically peaks at a distance greater than 300 ft. This will vary with headlamp variations, sheeting material, and sign placement.

Although the minimum luminance requirements of warning, regulatory, and other traffic control devices can often be met by retroreflective sheeting, a simple set of minimum standards has not been defined. Some general guidelines can be made. The No Passing Zone pennant and any other left-mounted sign should be constructed with Type III high-intensity sheeting. Overhead regulatory signs should probably be either Type IIa or Type III sheeting; overhead warning signs should be Type III. Roadside yellow diamond signs should generally be Type IIa or Type III to guarantee conspicuity because they are unexpected. These requirements may be relaxed at low operating speeds or in areas with low visual complexity.

Trade-offs Between Legibility and Conspicuity

One way of increasing conspicuity is to use materials of higher reflectivity. The limitations to this approach are the higher material cost and the reduction in legibility from irradiation. Increasing luminance increases legibility up to a point, after which overglow or irradiation begins to degrade it. The loss of legibility is difficult to document. Allen *(40)* reports the loss to be quite small and to occur only at very high levels of luminance. Others have shown irradiation to be more of a problem, particularly for older drivers *(39)*. When contrast is maintained within reasonable levels, irradiation should not be a problem; therefore, the luminance of fully reflectorized signs may be increased to aid conspicuity without sacrificing legibility. On partially reflectorized signs at high levels of luminance, the stroke width of white letters on black backgrounds should be decreased and the stroke width of black letters should be increased to offset the effects of irradiation *(39)*.

The luminance requirements for legibility and those for conspicuity are not always in agreement. A verbal sign may require more luminance for its legibility than for its conspicuity, because it requires a long MRVD. However, a symbol sign may require more luminance for its conspicuity because it subtends a larger visual angle than is necessary for legibility at the distance required. The 18-in. hazard marker with its 2.5-sec PRT is an example of a traffic control device whose luminance requirement should be responsive to the need for conspicuity.

Reduction of MRVD

Although attention should be given to providing adequate legibility at a distance through increased size and luminance of signs, other factors militate against using long MRVDs. Road design and geometry often reduce the visibility distance, so the sign must be very conspicuous and recognizable with a short MRVD. Also, long distances give older drivers the opportunity to become distracted and forget what action they are to take.

The use of multiple signs may reduce the MRVD requirement as well as the luminance threshold for conspicuity. Some signs and signing situations require that information be divided among two or more signs in order to reduce the time required for either recognition or decision making. Advanced directional signing facilitates an early decision concerning the exit a driver wants and its approximate location. The decision component, and therefore PRT, of subsequent signs is therefore shorter. Multiple signs have the added advantage of creating driver expectancies, which improve sign conspicuity.

Reducing the MRVD requirement may also be accomplished by redesigning a sign to make better use of symbols. Additional research relevant to symbols versus words and their relative effects on older drivers will be needed. Several studies suggest that the use of symbols may require more time by older drivers not familiar with them. Lindholm et al. *(18)* report that pattern goodness and spatial frequency interact with age to make generalization difficult. It may be that symbols reduce the MRVD for younger drivers and increase it for older drivers. Redundant symbol and word coding might be the best solution. This research is difficult to accomplish because the results of one sign message or symbol are not generalizable to others and individual differences are large.

Other Methods

As already mentioned, the easiest way to lower the perceptual threshold for conspicuity is to use advance warning signs. The brightness threshold for conspicuity is much less for drivers who know what to look for or where to look, or both. Although advance warning is useful, perhaps essential in some situations, multiple signing must not be allowed to create excess clutter.

The perceptual threshold for conspicuity may also be reduced by attention to sign placement. Although placement of signs in visually complex scenes cannot be avoided, sign placement has been mentioned as a factor that determines conspicuity. Attention should be given to the possibility of standardizing sign locations so that they are more readily seen. To some extent this is already being done on divided highways. The consistent use of advance guide signs and exit signing creates expectancies that should improve conspicuity. The use of a single sign to organize multiple service advertisements is a further step in this direction.

Lindholm et al. *(18)* suggest that standards for sign spacing and placement be based on information-processing speed and short-term memory capacity. They point out that the location of signs must give older drivers enough time to process the information and respond, but also that the information should not be presented so early that older drivers forget what they are to do. Another conclusion by Lindholm et al., which is consistent with our thesis that signs vary, is that driver requirements differ with the format and message of the sign and that optimal placement of a sign "may be both situation and sign specific." They conclude that "sign spacing and placement should be optimized with respect to the elderly driver's capacities."

Within the color coordinate values for signs there is room for variation that could be used to improve daytime contrast. Increasing saturation and decreasing lightness for a given hue will increase luminance and may result in more visible colors. The effect this has on nighttime luminance and color depends on the manufacturing process.

It is important to realize that many sign deficiencies are not the result of insufficient size, luminance, or contrast. Signs may be missing, bent, fallen, vandalized, and so on, and these problems can only be addressed by a formal system of review and inspection. It is not sufficient to simply erect adequate signs and forget about them. Better sign maintenance is essential to maintain safety for all drivers.

IMPLEMENTATION ISSUES

If the requirements of older drivers for sign legibility and conspicuity are to be met, change is required in a number of areas, including public policy, financing, and research.

Public Policy

The most serious public policy issues related to highway signing are licensing and definition of the design driver. Signing practice should be adequate to meet the needs of those licensed to drive. Although the needs of older drivers are addressed here, age is not the real issue. It is the need for a clear definition of the minimum skill and ability required to drive and of when this is impaired by reduced perceptual and cognitive skills. To determine impairment, a valid and efficient test must be developed to screen drivers and discriminate among safety-related driving behaviors. Such a test is not available now, and decisions must be made using the tests available.

Age is not an efficient predictor of driving performance. To avoid age discrimination, the cutoff level must be set too high to be effective. Aging is a gradual process. Impairments do not occur at once or at the same rate in different individuals; thus, signing should focus on impaired drivers and not a specific age group.

The practices of various states with regard to vision testing are discussed by Schieber and by Bailey and Sheedy elsewhere in this volume. The typical practice is to license drivers with 20/40 high-luminance acuity, which is roughly equivalent to 30 ft/in. of sign letter height. Given that many states do not retest, it is safe to assume that there are many drivers who are limited to reading signs at distances less than that.

There are alternatives to upgrading signs and revoking licenses. One is to restrict the time or location (or both) of driving for the impaired driver. Drivers could be given restricted licenses to discourage driving at night or on roads with poor signing and high volume. Another alternative that does not require testing and might be politically more acceptable is to post warnings on roads with insufficient signing.

In the final analysis the safety of all drivers can best be served by a combination of policies. Signing should be upgraded to meet the needs of as many drivers as possible. Licensing and other restrictions should be explored to deal with problems that signing cannot resolve.

Improved signing for older drivers would affect other drivers as well. Because the signing would be intended to compensate for impairment, all impaired drivers (including those temporarily impaired from the use of alcohol or drugs) would derive an immediate benefit. To the extent that safety is promoted, everyone shares in an indirect benefit from the improvements.

Solutions that require additional signing run the risk of conflicting with those concerned with the environment. Certainly a more cluttered highway is not desirable from the standpoint of beautification, cost, or information load on the driver. It is therefore important to attempt a comprehensive set of improvements. Such a program should result in the elimination of unnecessary signs and the grouping of other signs as well as the creation of some redundant and multiple signing. The concern should be the net effect of any sign improvement program on both safety and the environment.

The judicious use of placement and size may make more signs as attractive as fewer large signs. The collection of multiple service notices on single signs near Interstate exits enhances the appearance of the highway while continuing to serve the interests of motorists and merchants.

Cost Considerations

Several of the signing improvements mentioned in this paper would raise the cost of signing.

First, increasing sign size to maintain the legibility index at 40 ft/in. will increase sign costs because larger sign areas would often be required. Many signs, particularly those that use symbols, arrows, shapes, and so on, are of adequate size in current practice and would not need to be increased. However, it must be understood that increasing letter size by as little as a third may result in a 60 to 80 percent increase in the area of the sign needed to accommodate the larger letters.

Second, upgrading sign materials to provide greater reflectivity would increase costs. High-performance Type III sheeting costs about three times more than Type II sheeting. When the fixed costs of substrate, fabrication, hardware, transportation, and labor are considered, the cost ratio of Type III to Type II sheeting is about 1.5:1. When durability is considered in the comparison of life-cycle costs, Type III sheeting has been shown to be less expensive. Given the variability in durability reported by different states, life-cycle cost comparisons may have limited generalizability.

The third source of cost increase is the additional signing to achieve redundancy and advance warning. It must be remembered that this practice enables the use of smaller signs and also that a relatively small number of signs would be affected. After a careful analysis of signing requirements and placement, some signs will be found unnecessary and may be removed, offsetting to some extent the cost of additional signing.

The greatest expense in meeting the requirements of older drivers may be in sign maintenance. Inspection, washing, remounting, and replacement need to be given higher priority. Raising the priority of these activities will significantly raise the cost beyond the modest maintenance budgets normally allocated. Even if accident costs are unaffected by sign upgrades, the solution is likely to be cost-effective because of the reduction of tort liability awards.

The issue of tort liability needs to be explored and new legislation may be needed. It is hoped that the legal system could be used to encourage better signing and sign maintenance management. Administrators should be allowed to begin the process of upgrading signing without having to admit that the present system is unsafe and the consequential increase in liability. Agencies that do not have an effective sign maintenance management program should be more at risk than those that do.

Research Needs

It should be recognized that as the population ages, the problems of impaired drivers will intensify. This means that a long-term commitment is needed, not just a quick short-term response.

Research is needed to determine valid methods for measuring which visual, cognitive, and psychomotor impairments are associated with unsafe driving. Once the measurement methods have been developed, attention can be given to determining criteria for licensing.

Because factors that have no effect on younger drivers may have an effect on older drivers, research undertaken with young drivers as subjects should be reexamined with regard to the interactive effects of age.

The effect of signing methods needs to be tested on groups with different visual and cognitive functions and not on groups that differ in the amount they drive or when they drive. The results of such studies can then be projected to a highway system with any mix of driver characteristics, and generalizability to future driving patterns will be more direct.

Research is needed to derive an equivalent legibility index for specific symbols. Although much is known about the dimensions of symbols that improve recognition and discrimination, a firm understanding is needed of the visibility of the symbols currently in use. How does the recognition distance of any symbol compare with the legibility of an equivalent-size Series E letter?

As new manufacturing processes become available it may be possible to build signs with a border made of very high-intensity, narrow-angle sheeting intended for conspicuity and the sign background and message composed of wide-angle materials directed at legibility requirements. Research will be needed to test the effectiveness of this approach.

Research should be directed at the manipulation of color saturation and lightness to aid daytime visibility.

The MRVD model needs improvement and validation. The goal should be to make this model available to management so that they can use it to determine the distances at which signs in their inventory should be recognized.

Further research is needed on conspicuity. This research is difficult because of the effect of driver alertness on performance. What has been done should be redone with age as a factor. Critical variables to be studied include color, shape, contrast, visual complexity, driver expectancy, and eccentricity. The work must be repeated under daytime and nighttime conditions. The underlying dimensions of daytime visual complexity also need to be defined and the interaction of visual complexity with age should be explored.

A research program should begin that is directed at identifying those signing situations most in need of remediation. A special emphasis should be given to situations requiring short PRTs because of limited sight distances. Alternative solutions, including the use of symbols, placement, and multiple signing, should be explored. These solutions should be compared with regard to the reduction of PRT and then weighed against the alternative of providing greater visibility to satisfy the longer PRT.

CONCLUSIONS AND RECOMMENDATIONS

There appears to be a consensus in the literature that although basic visibility requirements must be met by providing signs of necessary size and luminance, the sign-related problems of older drivers require the highway community to do more than erect bigger and brighter signs. Improvements in sign management, multiple signing, placement, and other new approaches are critical.

The effects of age on visual processes suggest that signs should be installed with sufficient size to require no more than 40 ft/in. of legibility. Signs should be inspected to ensure that the physical condition of the sign and the mounting is maintained and that required contrast is retained. Sheeting of higher reflectivity should be used to achieve adequate conspicuity for critical purposes and where sign placement reduces luminance because of high observation and entrance angles.

The effects of age on information-processing time and short-term memory suggest that an effort be made to reduce the MRVD and specifically the PRT required for certain signing situations. This can be done through the use of symbols, color and shape codes, multiple signing, and placement.

The focus of most signing research has been on legibility and to some extent conspicuity. Although this research has been valuable, it should not be overlooked that such research is relatively easy to do. Research aimed at finding ways of reducing the MRVD through placement, multiple signing, and symbol messages is far more difficult to conduct and places more demands on the creativity of the research staff.

Standards and specifications should be reviewed to eliminate unjustifiable restrictions that may interfere with valid performance improvements. One example is the requirement of wide entrance angle performance for traffic control devices that must function only at narrow entrance angles. Another example is the need to reevaluate color coordinate values for highway signs to improve visibility.

Leadership is needed to ensure that the needed research is conducted, and the procurement process should be evaluated. The use of college students as subjects lowers costs and makes for more competitive bidding, but the answers needed to improve the safety of older people are not obtained. Changes should be made that would favor research plans including adequate testing of the effects on older drivers of any signing or other highway improvement.

REFERENCES

1. G. Hopper. *Inside Digital. Insight, News from Digital Equipment Corporation,* Vol. 7, No. 1, 1987.
2. L. K. Staplin. *Age-Related Diminished Capabilities and Driver Performance.* Working Paper. FHWA, U.S. Department of Transportation, Jan. 1985.
3. B. L. Neugarten. The Future and the Young-Old. *The Gerontologist,* Feb. 1975.
4. P. G. Koltnow. Improving Safety and Mobility for Older People. *TR News,* Sept.–Oct. 1985.
5. U.S. Congress. Senate. Special Commission on Aging. *Aging America: Trends and Projections.* 1985.
6. D. Solomon. The Older Driver and Highway Design. In *Needs and Problems of Older Drivers: Survey Results and Recommendations* (J. L. Malfetti, ed.), AAA Foundation for Traffic Safety, Falls Church, Va., Feb. 1985.
7. D. van der Zwagg. Induced Exposure as a Tool to Determine Passenger Car and Truck Involvement in Accidents. *HIT LAB Reports,* University of Michigan, 1971.
8. T. Maleck and J. Hummer. Driver Age and Highway Safety. In *Transportation Research Record 1059,* TRB, National Research Council, Washington, 1986, pp. 6–12.
9. D. Harrington and R. McBride. Traffic Violations by Type, Age, Sex, and Marital Status. *Accident Analysis and Prevention,* Vol. 2, 1970, pp. 67–79.
10. D. Yee. A Survey of the Traffic Safety Needs and Problems of Drivers Age 55 and Over. In *Needs and Problems of Older Drivers: Survey Results and Recommendations* (J. L. Malfetti, ed.), AAA Foundation for Traffic Safety, Falls Church, Va., Feb. 1985.
11. G. L. Gittings. Tort Liability in the Pennsylvania Department of Transportation. Presented at Conference on the Effectiveness of Highway Safety Improvements, Nashville, Tenn., March 1985.
12. D. J. Mace, R. S. Hostetter, L. E. Pollack, and W. P. Zweig. *Minimal Luminance Requirement for Official Highway Signs.* Report FHWA/RD-86-151. FHWA, U.S. Department of Transportation, May 1986.
13. G. J. Alexander and H. Lunenfeld. *Positive Guidance in Traffic Control.* FHWA, U.S. Department of Transportation, April 1975.
14. H. W. McGee, W. Moore, B. G. Knapp, and J. H. Sanders. *Decision Sight Distance and Traffic Control Requirements.* Report FHWA-RD-78-78. FHWA, U.S. Department of Transportation, Feb. 1978.
15. F. I. Awadallah. Durability of Retroreflectance Signs. Doctoral dissertation, University of Maryland, College Park, 1987.
16. D. G. Pitts. In *Aging and Human Visual Function,* Alan R. Liss, Inc., New York, 1982.
17. J. H. Carter. In *Aging and Human Visual Function,* Alan R. Liss, Inc. New York, 1982.
18. J. M. Lindholm, H. H. Young, and A. E. Radwan. *Visual Processing and Driving Safety.* Report ADOT HPR-1-23. Arizona State University, Tempe, 1987.
19. A. M. Milone. Training and Retraining the Older Driver. In *Needs and Problems of Older Drivers: Survey Results and Recommendations* (J. L. Malfetti, ed.), AAA Foundation for Traffic Safety, Falls Church, Va., 1985.
20. A. J. Yanik. *How Aging Affects the Relationship Between the Driver and the Road Environment.* SAE Technical Paper. Society of Automotive Engineers, Warrendale, Pa., in press.
21. J. G. Ells and R. E. Dewar. *Human Factors,* Vol. 21, No. 2, 1979, pp. 161–168.

22. R. J. Jacobs, A. W. Johnston, and B. L. Cole. The Visibility of Alphabetic and Symbolic Traffic Signs. *Australian Road Research*, Vol. 5, No. 7, 1975, pp. 68–86.
23. P. L. Olson and M. Sivak. Perception-Response Time to Unexpected Roadway Hazards. *Human Factors*, Vol. 28, No. 1, 1986, pp. 91–96.
24. B. L. Cole and S. E. Jenkins. *Conspicuity of Traffic Control Devices*. Internal Report AIR 218-1. Australian Road Research Board, Nunawading, Victoria, 1978.
25. K. Perchonok and L. Pollack. *Luminous Requirements for Traffic Signs*. Interim Report. Institute for Research, State College, Pa., Dec. 1981.
26. D. J. Mace, R. B. King, and G. W. Dauber. *Sign Luminance Requirements for Various Background Complexities*. Report FHWA/RD-85/056. FHWA, U.S. Department of Transportation, Feb. 1984.
27. D. J. Mace and L. Pollack. Visual Complexity and Sign Brightness in Detection and Recognition of Traffic Signs. In *Transportation Research Record 904*, TRB, National Research Council, Washington, D.C., 1983, pp. 33–41.
28. S. E. Jenkins. Consideration of the Effects of Background on Sign Conspicuity. *Proc., Australian Road Research Board*, Vol. 2, 1981.
29. B. L. Cole and S. E. Jenkins. *The Effect of Size and Luminance on Visual Conspicuity in the Road Traffic Environment*. Internal Report AIR 218-3. Australian Road Research Board, Nunawading, Victoria, 1979.
30. V. J. Roper and E. A. Howard. Seeing with Motor Car Headlamps. *Transactions of the Illuminating Engineering Society*, Vol. 33, No. 5, May 1938.
31. W. S. Ferguson and K. E. Cook. Driver Awareness of Sign Colors and Shapes. *Highway Research Analysts*, 1966.
32. T. W. Forbes, R. F. Pain, R. P. Joyce, and J. P. Fry, Jr. Color and Brightness Factors in Simulated and Full-Scale Traffic Sign Visibility. In *Highway Research Record 216*, HRB, National Research Council, Washington, D.C., 1968, pp. 55–65.
33. P. Odescelchi. Conspicuity of Signs in Rural Surroundings. *Traffic Engineering and Control*, Vol. 2, 1960, p. 390.
34. S. E. Jenkins and B. L. Cole. *A Note on the Role of Colour in Conspicuity*. Internal Report, AIR 213-4. Australian Road Research Board, Nunawading, Victoria, 1979.
35. M. Sivak and P. L. Olson. Optical and Minimal Luminance Characteristics for Retroreflective Highway Signs. In *Transportation Research Record 1027*, TRB, National Research Council, Washington, D.C., 1985, pp. 53–57.
36. P. L. Olson and A. Bernstein. The Nighttime Legibility of Highway Signs as a Function of Their Luminance Characteristics. *Human Factors*, Vol. 21, 1979, pp. 145–160.
37. M. Sivak, P. L. Olson, and L. A. Pastalan. Effect of Driver's Age on Nighttime Legibility of Highway Signs. *Human Factors*, Vol. 23, 1981, pp. 59–64.
38. D. W. Evans and A. P. Ginsburg. *Human Factors*, Vol. 27, No. 6, 1985, pp. 637–642.
39. P. L. Olson, M. Sivak, and J. C. Egan. *Variables Influencing the Nighttime Legibility of Highway Signs*. Report UMTRI-83-36. University of Michigan Transportation Institute, Ann Arbor, June 1983.
40. T. M. Allen. Night Legibility Distances of Highway Signs. *Bulletin 191*, HRB, National Research Council, Washington, D.C., 1958, pp. 33–40.
41. T. W. Forbes and R. S. Holmes. Legibility Distances of Highway Destination Signs in Relation to Letter Height, Width, and Reflectorization. *HRB Proc.*, Vol. 19, 1939, pp. 321–326.
42. T. W. Forbes, K. Moskowitz, and G. Morgan. A Comparison of Lower Case and Capital Letters for Highway Signs. *HRB Proc.*, Vol. 30, 1950, pp. 355–373.