area with low electric rates to $305.02 for a sign maintained by a contractor in an area with high electrical rates. The average annual cost was $160.35/sign. This annual expense is greater than the additional investment required to build signs with encapsulated-lens reflective materials rather than with the conventional enclosed-lens sheeting. Because the service life of encapsulated-lens materials exceeds 10 years, a benefit-cost ratio greater than 10 to 1 can be anticipated for signs mounted on existing structures and refurbished with encapsulated-lens reflective sheeting.

If the existing 520 signs located on straight approaches were refurbished with encapsulated-lens materials and the lights disconnected, there would be an annual saving of approximately $83 000 in electrical and maintenance costs. This saving does not include other benefits, such as the reduced exposure of maintenance personnel to traffic, improved services to motorists, the availability of maintenance crews and equipment for other work, and the reduction in time required for night inspections to locate malfunctioning lights.

Eliminating the lighting on new overhead sign structures would result in enormous savings in installation costs. Because overhead signs are usually located on straight sections of roadways, the number of proposed signs that meet the visibility-recognition criterion is increasing. Fifty percent of these signs will be located on straight approaches, where the illumination could be eliminated if they were made with encapsulated-lens sheeting. On the sign project proposed for I-495, the elimination of lights on the overhead structures could save $7030/structure (less $400 to $500 for the additional expense of the encapsulated-lens sheeting). The saving for the entire project would be more than $500 000, and greater savings per structure could be anticipated on projects that require a small number of signs and in areas where the power sources are long distances from the overhead signs.

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The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.

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Poor Visibility Under Low-Beam Headlights: A Common Cause of Wrong-Way Driving

N. K. Vaswani, Virginia Highway and Transportation Research Council, Charlottesville

Through selected case studies, this paper illustrates the way in which the inadequate visibility of road signs and pavement markings at night contributes to wrong-way driving. A concept termed the keg of legibility, which delineates the limits of nighttime visibility under low-beam headlights, is described. The application of the keg-of-legibility concept to the placement of signs, markings, and additional devices that help guide the motorist through the intersection of a four-lane divided highway and another road is discussed. Examples of wrong-way entry on roads having poor geometrics are used to emphasize the need for such guidance.

Surveys of wrong-way driving in Virginia since 1970 have shown that most of the wrong-way incidents originated at interchanges and intersections. A driver must be very carefully guided onto the correct ramp at an interchange or around the nose of the median when he or she is making a left turn at an intersection on a divided highway. Many information devices, such as signs and pavement markings, and other features such as curbs, often made conspicuous by color, are used to provide this guidance, but they are often not of maximum effective-

Figure 1. Ten-degree cone of vision.

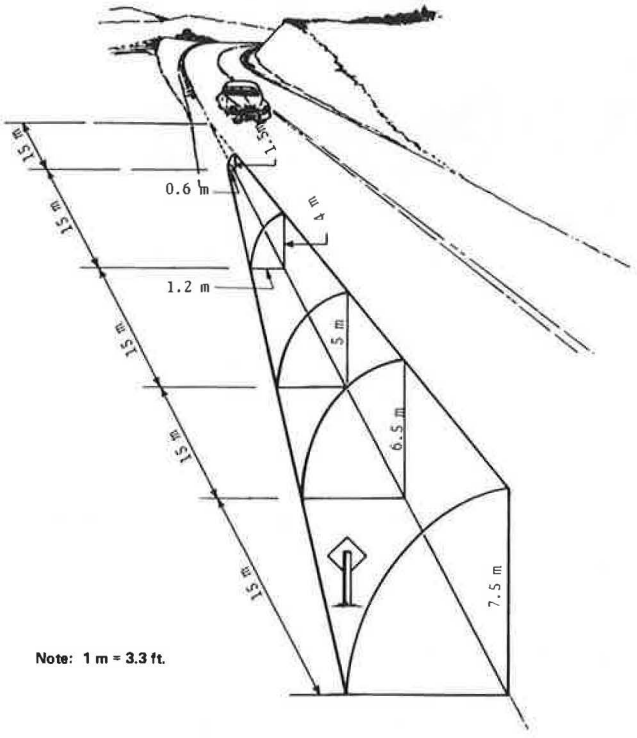


Figure 2. Keg of legibility of sign under low-beam headlights.

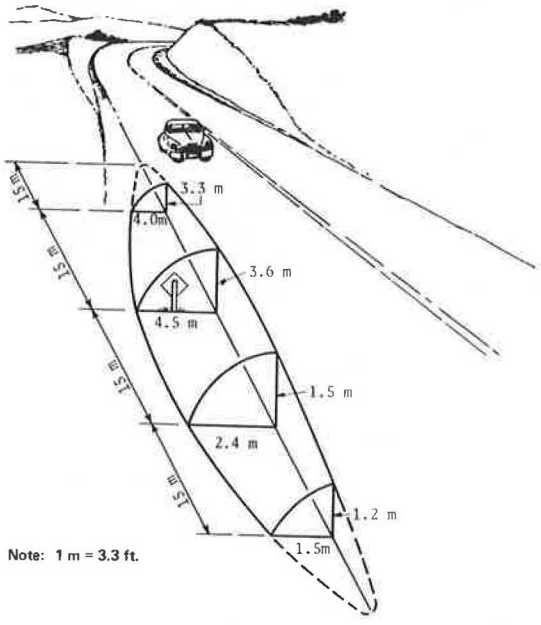


Figure 3. Daytime photograph of intersection of Interstate exit ramp and secondary road.

ness for a driver using low-beam headlights at night, either because of improper location of them or because of poor geometrics of the intersection.

NEED FOR DESIGN BASED ON NIGHT VISIBILITY

The longitudinal and transverse distances at which most traffic-control and guidance elements at intersections can be seen during the day are limited only by sight distances. However, at an unlighted intersection at night, these distances are limited by the following additional factors:

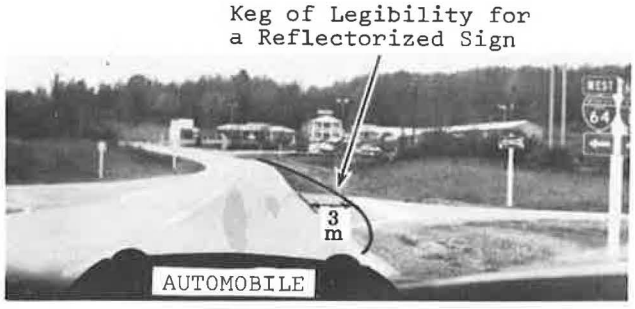
1. The area illuminated by the headlights, which are usually on low beam,
2. The size and shape of the object to be viewed,
3. The luminance and contrast of the roadway elements, and
4. The luminance of the details of the object and their contrast with their background.

Thus, roadway devices located on the basis of their daytime visibility and legibility may not be visible or legible at night, and the motorist is then left with only a limited number of them, or none at all, for guidance. Therefore, for full effectiveness, highway devices provided for guidance should be designed and located on the basis of their legibility under low-beam headlights at night.

The present concept of the field of vision of a driver is based on the cone of vision. According to Pignataro (1), the limit of far clear sight is that within a cone of 10 to 12°. Figure 1 shows a 10° cone of vision and the vertical and horizontal distances from the pavement edge within which, according to the cone concept, a sign would

Figure 4. Nighttime photograph of intersection shown in Figure 3.

Figure 5. Keg of legibility for intersection shown in Figures 3 and 4.



Note: 1 m = 3.3 ft.

Figure 6. Daytime photograph of partial cloverleaf intersection of Interstate exit ramp and primary highway.

Figure 7. Nighttime photograph (low-beam headlights) of intersection shown in Figure 6.

be visible. This concept, however, is based on daytime vision.

The nighttime and daytime legibility of a 0.6 by 0.6-m (2 by 2-ft) reflectorized diagrammatic sign made of engineering-grade sheeting was evaluated. The sign was placed 0, 1.5, 3.0, or 4.5 m (0, 5, 10, or 15 ft) from the pavement edge, with its center 1.5, 2.4, or 3.3 m (5, 8, or 11 ft) above the road level. Nighttime and daytime photographs of it were taken at each combination of placements from distances of 15, 30, 45, 60, and 75 m (50, 100, 150, 200, and 250 ft). The lens of the camera was 1.2 m (4 ft) above the road surface and 2.7 m (9 ft) from the pavement edge. At night, low-beam headlights were used.

These photographs were projected in a darkened room before five persons who graded the legibility (poor, fair, good, or excellent) of the sign. The limits of good legibility in terms of depth, height, and distance from the pavement edge determined in this way are shown diagrammatically in Figure 2. This diagram shows that the zone of good legibility at night is not conical (as shown in Figure 1) but keg shaped. For example, a sign in a quadrant of an 4.5 by 3.6-m (15 by 12-ft) oval with its axis on the pavement edge should be legible to a driver 30 m (100 ft) away, and its legibility would still be good even if its distance from the pavement edge were increased to 1.5 m (5 ft). The maximum distances from the pavement edge within which the sign would still be legible to a driver 15 or 30 m (50 or 100 ft) away are 3 and 3.6 m (10 and 12 ft) respectively. Hence, for intersections at which the distance between the stopping point of the driver and the median (where the signs are located) is less than 30 m (100 ft), the maximum distance from the pavement edge for the placement of a sign can be taken as 3 m (10 ft).

This keg of legibility is that for a normal person driving with low-beam headlights in good weather conditions on a straight road. Its size will decrease with defective headlights, increased humidity, and fog and rain. It could, however, be increased by the use of high-intensity sheeting rather than engineering-grade sheeting.

ROADS INTERSECTING AT SAME ELEVATION

The following two cases, in which the drivers entered the exit ramp of the Interstate rather than the entry ramp, resulted from poor visibility of the signs and roadway markings.

Case 1—Intersection of Interstate Highway Exit Ramp and Secondary Road

Figures 3 and 4 are daytime and nighttime photographs of an exit ramp at the intersection of an Interstate highway and a secondary road, where a wrong-way entry occurred. Two things are evident from the photographs.

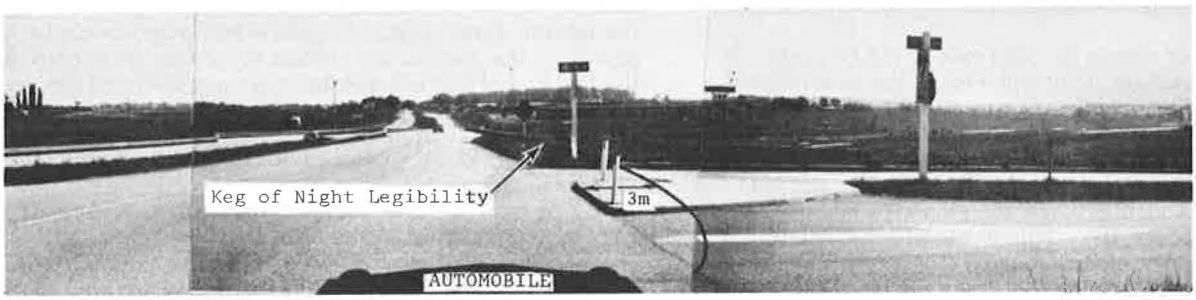
Figure 4 shows that, because of the restricted depth and width of vision at night, a driver with low external stimuli may be guided by the line at the edge of the pavement, which flares into the right lane. The continuation of this line straight across the ramp pavement might discourage a wrong-way entry at night. Or, an alternative way to prevent such an entry would be to place the stop line sufficiently close to the crossroad to put it within the zone illuminated by low-beam headlights, i.e., within the keg of nighttime legibility (2, 3). Either of these alternatives might channelize the movements of drivers, especially those with low external stimuli, and provide a pseudo-pavement-edge effect.

A comparison of Figures 3 and 4 shows that the one-way arrow sign and the stop line, which are visible to the daytime driver, are not visible at night. If drivers can function at night without the benefit of a particular sign, this sign evidently has no use during the daytime also. Hence, the locations of signs should be based more on their nighttime than on their daytime visibility. This one-way sign and the stop line should have been located within the keg of nighttime legibility, which is shown in Figure 5.

Case 2—Intersection of Interstate Highway Ramps and Primary Highway

Figure 6 is a daytime photograph of a partial cloverleaf (parclo) interchange between the exit and entry ramps of an Interstate highway and a divided primary highway, where a wrong-way entry occurred. The nose of the median between the exit and entry ramps is set back from the junction and, as shown in Figure 7, is not visible at night. If the nose were made visible at night it would show the separation between the exit and the entry ramps and thus would reduce the probability of a driver entering the exit rather than the entry ramp. The following improvements are recommended for a parclo inter-

Figure 8. Keg of legibility for intersection shown in Figures 6 and 7.



Note: 1 m = 3.3 ft.

Figure 9. Intersection of primary divided highway and secondary road at differing elevations (cross section across four-lane divided intersection extended into crossroad).

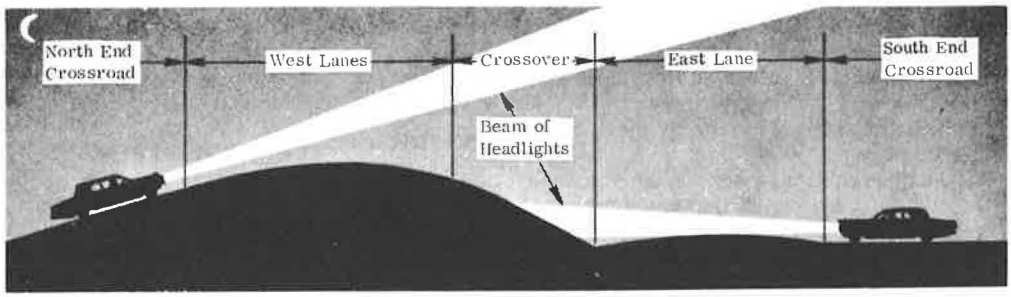
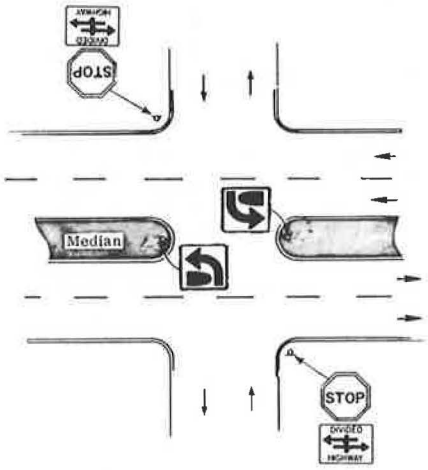


Figure 10. Recommended traffic signs for discouraging wrong-way entry.



change in which the exit and entry ramps are very close to each other.

1. The nose of the median should be extended to the edge of the crossroad so that it is within the keg of nighttime legibility, and it should be made of concrete and painted with reflective paint. It should also be marked by delineators, which should be within the keg of nighttime legibility. Figure 8 shows the suggested improvement with the portion of the nose that would be visible at night. Such a nose would provide proper visibility, separate the exit and the entry ramps, and fully channelize the exit ramp and thus discourage drivers from entering the exit ramp from the crossroad.
2. Either the pavement edge line should be continuous across the exit ramp, or the stop line should be close to the edge of the crossroad so that it is within the keg of nighttime legibility.
3. The pavement edge line should be flared into the entry ramp to encourage drivers to maneuver properly.

INTERSECTING ROADS AT DIFFERENT ELEVATIONS

General Cases

The two commonest problems involving the geometrics at nonlevel intersections are described below.

1. The crossroad slopes down from the divided highway. Sometimes the slope is so steep that little or no light from the headlights of an automobile approaching the divided highway falls on it. An example is shown in Figure 9.
2. The opposing lanes of the divided highway are at different elevations. A driver coming from the crossroad cannot see both sides of the divided highway with low-beam headlights and may consider it to be a two-lane road and the median to be the opposite edge of the road.

These problems are compounded when they are combined at one intersection. The steeper the downward slopes of the crossroads or the greater the difference between the elevations of the two opposite lanes of the divided highway, the poorer is the visibility.

Case 3—Intersection of Divided Primary Highway and Secondary Road

The intersection shown by the cross-sectional sketch in Figure 9 is the site of two wrong-way entries (both by nondrunken drivers): One entry was during the day from the northern side of the crossroad, and the other was at night from the southern side of the crossroad. As is shown in this figure, the northern side of the crossroad slopes down from the divided highway, and there is a considerable difference in elevation between the east and the westbound lanes of the divided highway. The southern side of the crossroad is, however, level with the eastbound lane of the divided highway.

Thus, a driver approaching the intersection from the

northern side of the crossroad cannot see the highway. This kind of intersection could be improved as follows.

1. A driver should be informed of the geometry of the roadways before he or she enters the intersection. This can best be done by placing a diagrammatic sign depicting a divided highway intersection so that it is visible to a driver using low-beam headlights at night, when the need to know the geometry is greatest. The best location for this sign is below the stop sign and on the same pole (Figure 10). This would place it within 3 m (10 ft) of the edge of the lane and thus within the keg of nighttime visibility. Signs of this type have been installed on an experimental basis at intersections on 92 km (57 miles) of primary highways in Virginia. They have also been used in Delaware, where it is claimed that wrong-way entries have been reduced (according to a letter of August 7, 1976, from Raymond S. Pusey of the Delaware Bureau of Traffic to the Federal Highway Administration). It is not an international sign nor has it been approved for incorporation in the Manual on Uniform Traffic Control Devices by the U.S. Department of Transportation.
2. At intersections such as the one shown in Figure 9, the nose of the median that the driver must negotiate in making a left turn is not visible to him or her at night, and it may be necessary to provide guidance for this maneuver. This information is in addition to the divided-highway-intersection sign, and a suitable sign is also shown in Figure 10.

CONCLUSIONS

1. The locations of road signs and pavement markings should be designed on the basis of their nighttime visibility rather than their daytime visibility.
2. Diagrammatic signs should be used to provide guidance at intersections having poorly designed features, such as differences in elevation between the opposite lanes of four-lane divided highways, crossroads that slope down from divided highways, or wide crossovers that could lead to wrong-way entries. A diagrammatic sign depicting a divided-highway intersection should be placed below the stop sign at the junction of a crossroad and a divided highway to inform the driver of the geometry of the intersection. A diagrammatic turn sign should be placed on the nose of the median to inform the driver of the location of the left-median nose and the need for turning around it.
3. The application of the cone-of-vision concept for the placement of signs should be modified to include the keg-of-nighttime-legibility concept.
4. At intersections of crossroads and highway exit ramps, the marking on the edge of the pavement of the crossroad should be continued across the exit, or the stop line on the exit ramp should be brought within the keg of nighttime legibility of a driver on the crossroad.
5. On parclo interchanges having the exit and entry ramps very close together, the median should extend to the edge of the crossroad, and its nose should be made of concrete and painted with reflective material. This will make the nose conspicuous in the keg of legibility, show the separation between the exit and entry ramps near the crossroad, and channelize traffic from the exit ramp.

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