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MAINTAINED NIGHT-TIME VISIBILITY OF RETROREFLECTIVE ROAD SIGNS

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Maintained Night-time Visibility of Retroreflective Road Signs

Table of Contents

	Page
1. Introduction	1
1.1 Terminology	1
2. Sign luminance and retroreflectivity	2
2.1 Factors affecting retroreflective sign luminance	3
2.1.1 Sign luminance replacement factors	3
2.1.2 Geometric factors	3
2.1.2.1 Entrance angle	3
2.1.2.2 Observation angle	4
2.2 Ideal conditions	5
2.3 Sign factors	6
2.3.1 Retroreflective signing material types	6
2.3.2 Sign colour	7
2.3.3 Fog, dew, and rain	9
2.3.4 Dirt	9
2.3.5 Weathering	9
2.3.5.1 Weathering performance, Australia	10
2.3.5.2 Weathering performance, United States	11
2.3.5.3 Laboratory weathering tests	13
2.3.5.4 Outdoor test deck weathering	13
2.3.6 Sign criticality/functionality factors	13
2.4 Roadway factors	13
2.4.1 Roadway curvature	13
2.4.2 Roadway width	13
2.4.3 Sign position	14
2.4.4 Small signs	15
2.4.5 Last look distance	15
2.4.6 Surround	15
2.4.7 Headlamp glare	16
2.5 Vehicle factors	16
2.5.1 Headlamp beam pattern	16
2.5.2 Headlamp beam usage	17
2.5.3 Headlamp quality	17
2.5.4 Windshield absorption	18
2.6 Driver factors	18
2.6.1 Visual acuity	18

2.6.2	Driver age and visual status	18
2.6.3	Driver experience and expectation	20
3.	Developing minimum visibility criteria	21
3.1	Minimum required sign luminance and retroreflectivity	21
3.1.1	Determination of sign luminance	21
3.1.2	Summary of studies of minimum sign luminance	21
3.1.2.1	Review of sign legibility studies	21
3.1.2.2	Terminal values of road signs	22
3.1.2.3	Minimum required visibility, USA	27
3.1.2.4	Evaluation of visibility distance, France	31
3.2	Allowances for degraded conditions	32
3.3	Sign visibility policies and implementation	32
3.3.1	Existing policies	32
3.3.2	Implementation	32
3.3.3	Future policy	33
4.	Field evaluation of retroreflective sign performance	34
4.1	Subjective evaluation techniques	34
4.2	Portable instruments	34
4.3	Mobile instrumentation	34
4.3.1	Luminance instruments	34
4.3.2	Retroreflectance instruments	35
4.4	Evaluation of colour	35
4.5	Sign dating	36
5.	Maintaining system-wide visibility	37
5.1	Collection of sign inventory data	37
5.2	Software of inventory data	37
6.	Recommendations	39
6.1	Inspection of signs	39
6.1.1	Night-time inspection steps	39
6.1.2	Daytime inspection steps	39
6.2	Minimum photometric performance for replacement of retroreflective road signs	40
7.	Appendices	44
7.1	Determination of sign luminance from retroreflectance	44
7.1.1	Example calculation of sign luminance	45
7.1.2	Direct measurement	50
7.2	Determination of retroreflectance from luminance	50
7.2.1	Correlational estimate	51
7.3	Headlamp output tables	51
8.	References	54

CIE 113-1995

MAINTAINED NIGHT-TIME VISIBILITY OF RETROREFLECTIVE ROAD SIGNS**Summary**

The visual information provided by road signs gives the motorist fundamental instructions governing the selection of routes, safety at intersections, warning of physical obstructions, and delineation of a safe path for travel. Signs are the primary means of communication from the road authorities to the motorist about roadway conditions. Signs must govern safe and comfortable travel both in daytime and at night.

Official traffic control devices are made visible at night by providing a retroreflective surface, retroreflective buttons, or, in some cases by separate illumination. This preserves the essential visual cues necessary for night-time operation: the discrimination of the sign from the night-time surroundings by its unique colour, shape and legend.

Once many such devices have been installed and have been in service for a number of years, degradation of this important system will occur. The degradation of road sign performance occurs from a number of causes: obsolescence, theft, vandalism, accident, visual obstruction, and the effects of weathering. A continual maintenance effort by authorities is required to ensure timely replacement. Although replacement of stolen signs, vandalised signs or those rendered obsolete by changing regulation is accomplished from reports by police and by routine daytime inspections, the loss of night-time visual performance from the effects of natural weathering is often difficult to discern in daytime and eventually will lead to the gradual degradation of the remaining signs. The night-time effectiveness may then become seriously impaired.

This report covers those retroreflective signs dependent on headlamp illumination and provides information on the replacement point for retroreflective signs degraded from the effects of weathering. If sign replacement is not necessitated by any other cause, an eventual loss of night-time luminance and visibility will result from the effects of weathering.

Although this may seem like a simple matter, a satisfactory operational level of visibility is made complex by the variable nature of the response required by the sign, the surroundings in which the sign is seen, the driver's vision, and the illuminance provided by the vehicle.

Because of the very large number of retroreflective road signs and the driver's dependence on their functionality, research has identified a number of factors concerning the maintenance of the visual effectiveness of retroreflective signs. The research includes a number of important elements: the determination of the minimum retroreflectance which can provide an adequately functional level of night-time performance; the prediction of this end point to provide a means of scheduling replacement; means of inspection and providing an inventory; and, ultimately, a systematic method for obtaining the maximum value for each annual expenditure.

The principles described in this report may be applied to other signing applications such as signs employed on railways and waterways.

VISIBILITÉ DE NUIT DES PANNEAUX ROUTIERS RÉTRORÉFLÉCHISSANTS**RÉSUMÉ**

Les informations visuelles fournies par les panneaux de signalisation donnent aux conducteurs de véhicules routiers des informations fondamentales concernant le choix des itinéraires, la sécurité des intersections, l'annonce d'obstacles physiques et le tracé de la voirie. Les panneaux sont les principaux moyens de communication entre les services routiers et les conducteurs. Les panneaux routiers doivent permettre aux conducteurs de se déplacer confortablement et en toute sécurité aussi bien de jour que de nuit.

Les panneaux routiers réglementaires sont rendus visibles de nuit par l'utilisation de surfaces rétroréfléchissantes, de boutons rétroréfléchissants, ou bien dans certains cas par des éclairages spécifiques. Cela préserve les informations essentielles pour la conduite de nuit: c'est à dire la reconnaissance de ces signaux dans l'obscurité environnante par leurs couleurs, leurs formes et leurs légendes.

Lorsque ces panneaux sont installés et mis en service pendant de nombreuses années, une dégradation de cet important système d'information survient. La dégradation de la performance des panneaux routiers provient de nombreuses causes: obsolescence, vol, vandalisme, accident, obstruction visuelle et effet des agents atmosphériques. Un effort continu pour l'entretien de ces

panneaux par les autorités routières est nécessaire pour pouvoir en assurer le remplacement en temps utile. Bien que le remplacement de panneaux volés, vandalisés ou rendus obsolètes par le changement de la réglementation routière, soit fait suite aux rapports de police ou aux inspections de routine de jour, la perte de l'efficacité visuelle nocturne des panneaux qui restent, due aux agents atmosphériques, est souvent difficile à détecter pendant la journée, et peut éventuellement entraîner la dégradation de ces panneaux résiduels. Leur efficacité nocturne peut en effet être sérieusement compromise.

Ce rapport concerne les panneaux routiers rétro réfléchissants qui dépendent de l'éclairage des seuls feux de véhicules et fournit des informations relatives aux seuils de remplacement de ces panneaux dégradés par les effets des agents atmosphériques. Si le remplacement des panneaux routiers n'est pas fait pour une autre raison, la perte éventuelle de leur luminance nocturne et de leur visibilité résulte des agents atmosphériques.

Bien que cela paraisse être une chose simple à faire, le maintien d'un niveau satisfaisant de la visibilité de ces panneaux est rendu complexe par la nature variable de leur fonctionnement: l'environnement dans lequel les panneaux sont perçus, la vision du conducteur, et l'éclairage provenant des projecteurs des véhicules.

A cause du très grand nombre de panneaux routiers rétro réfléchissants et de la dépendance des conducteurs vis à vis de leur fonctionnement photométrique, la recherche a identifié un certain nombre de facteurs relatifs au maintien de l'efficacité visuelle des panneaux rétro réfléchissants: la détermination d'un coefficient de rétro réflexion minimal correspondant à un niveau de fonctionnement convenable de nuit, l'utilisation de ce seuil permettant la prévision du remplacement des panneaux, les moyens d'inspection et de recueil de données, et en dernier lieu, une méthode systématique pour obtenir une valeur maximale du budget d'entretien annuel.

Les principes décrits dans ce rapport peuvent être appliqués aux autres panneaux tels que les panneaux ferroviaires et fluviaux.

NACHTSICHTBARKEIT VON RETROREFLEKTIERENDEN STRASSENVERKEHRSZEICHEN IM GEBRAUCH

Zusammenfassung

Die durch Straßenverkehrszeichen vermittelten optischen Informationen geben dem Kraftfahrer grundlegende Hinweise und Gebote für die Auswahl seiner Fahrtroute, das Verhalten an Straßenkreuzungen, eine Warnung vor Hindernissen und die Gewährleistung einer sicheren Fahrt. Straßenverkehrszeichen sind die wesentlichen Kommunikationsmittel zwischen den Straßenverkehrsbehörden und dem Kraftfahrer, sie müssen eine sichere und angenehme Fahrt bei Tag und Nacht gewährleisten.

Straßenverkehrszeichen werden bei Nacht durch eine retroreflektierende Oberfläche, Rückstrahler oder auch in einigen Fällen durch eine eigene Beleuchtung sichtbar gemacht. Diese Maßnahmen enthalten die wesentlichen Informationen, die für ihre Verwendung bei Nacht notwendig sind: die Unterscheidung des Verkehrszeichens von der nächtlichen Umgebung durch seine Farbe, Form und Beschriftung.

Wenn Verkehrszeichen einmal installiert worden sind, beginnt nach einigen Jahren der Verschleiß dieses wichtigen Kommunikationssystems. Die verminderte Wirksamkeit der Verkehrszeichen hat mehrere Ursachen: Diebstahl, Vandalismus, Unfälle, optische Behinderung und Verwitterung. Um einen regelmäßigen Austausch sicherzustellen, ist eine ständige Wartung durch die Straßenverkehrsbehörden notwendig. Obwohl der Ersatz von entwendeten, beschädigten oder durch geänderte Verkehrsvorschriften überflüssig gewordenen Zeichen durch Polizeimeldungen und turnusmäßige Verkehrszeichenschauen bei Tage sichergestellt ist, ist der durch natürliche Verwitterung bedingte Verlust der Retroreflexion bei Tage nur sehr schwer festzustellen und führt zu einem schrittweisen Verschleiß der Verkehrszeichen. Die Erkennbarkeit dieser Zeichen kann dann bei Nacht ernsthaft beeinträchtigt sein.

Der vorliegende Bericht befaßt sich mit retroreflektierenden Verkehrszeichen, die vom Kraftfahrzeugscheinwerfer angestrahlt werden müssen, und gibt Informationen über den Zeitpunkt für den Austausch retroreflektierender Verkehrszeichen, die durch Verwitterung verschliffen sind. Wenn der Ersatz von Zeichen nicht aus irgendeinem anderen Grund für notwendig erachtet wird, wird doch ein schrittweiser Verlust der Nachtsichtbarkeit durch Verwitterung eintreten.

CIE 113-1995

Obgleich das Problem einfach erscheint, wird ein zufriedenstellendes Sichtbarkeitsniveau durch die unterschiedlichen Anforderungen an das Verkehrszeichen, das Umfeld, das Sehvermögen des Kraftfahrers und die Beleuchtung durch den Kraftfahrzeugscheinwerfer komplex.

Wegen der sehr großen Anzahl retroreflektierender Verkehrszeichen und der Abhängigkeit des Kraftfahrers von deren Funktionstüchtigkeit sind Untersuchungen durchgeführt worden, die zu einer Anzahl von Ergebnissen hinsichtlich der Wirksamkeit der Zeichen geführt haben. Diese Untersuchungen umfaßten eine Anzahl bedeutender Themen: die Bestimmung des Minimums der erforderlichen Retroreflexion, die ein adäquates Niveau der Nachtsichtbarkeit sicherstellen kann, die Vorhersage dieses Endes, um eine Methode für die Planung von Austauschmaßnahmen zu schaffen, Gebrauchsanweisung für Inspektion und Inventarisierung und schließlich eine systematische Methode zur Optimierung der jährlich anfallenden Kosten.

Die in diesem Bericht beschriebenen Prinzipien können auch für andere Verkehrszeichen, wie z.B. im Eisenbahnwesen und in der Schifffahrt, angewendet werden.

1. INTRODUCTION

The visual information provided by road signs gives the motorist fundamental instructions governing the selection of routes, safety at intersections, warning of physical obstructions, and delineation of a safe path for travel. Signs are the primary means of communication from the road authorities to the motorist about roadway conditions. Signs must govern safe and comfortable travel both in daytime and at night.

Official traffic control devices are made visible at night by providing a retroreflective surface, retroreflective buttons, or, in some cases by separate illumination. This preserves the essential visual cues necessary for night-time operation: the discrimination of the sign from the night-time surroundings by its unique colour, shape and legend.

Once many such devices have been installed and have been in service for a number of years, degradation of this important system will occur. The degradation of road sign performance occurs from a number of causes: obsolescence, theft, vandalism, accident, visual obstruction, and the effects of weathering. A continual maintenance effort by authorities is required to ensure timely replacement. Although replacement of stolen signs, vandalised signs or those rendered obsolete by changing regulation is accomplished from reports by police and by routine daytime inspections, the loss of night-time visual performance from the effects of natural weathering is often difficult to discern in daytime and eventually will lead to the gradual degradation of the remaining signs. The night-time effectiveness may then become seriously impaired.

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Although this may seem like a simple matter, a satisfactory operational level of visibility is made complex by the variable nature of the response required by the sign, the surroundings in which the sign is seen, the driver's vision, and the illuminance provided by the vehicle.

Because of the very large number of retroreflective road signs and the driver's dependence on their functionality, research has identified a number of factors concerning the maintenance of the visual effectiveness of retroreflective signs. The research includes a number of important elements: the determination of the minimum retroreflectance which can provide an adequately functional level of night-time performance; the prediction of this end point to provide a means of scheduling replacement; means of inspection and providing an inventory; and, ultimately, a systematic method for obtaining the maximum value for each annual expenditure.

The principles described in this report may be applied to other signing applications such as signs employed on railways and waterways. It is not intended to be applied to pavement markings or delineators.

1.1 Terminology

The terminology according to the International Lighting Vocabulary, CIE 17.4-1987, is used in this report. For the phenomenon reflection it is usual to distinguish between the quantities *reflectance*, the dimensionless ratio of two radiometric/photometric quantities (e.g. two fluxes) and *reflectivity*, the reflectance if the material is thick enough so that no change of reflectance occurs if the material thickness is further increased. In case of retroreflection it is meaningless to speak about an increase of material thickness, thus both terms retroreflectance and retroreflectivity will be used.

2. SIGN LUMINANCE AND RETROREFLECTIVITY

For drivers to operate safely at night assumes a comfortable level of visibility commensurate with the allowable speed. To accomplish this, essential roadway guidance features such as signs and markings, are made visible by vehicle lighting, and, in the absence of public or sign illumination, by retroreflective treatments. The many considerations of visibility and design of signs to transmit information to the user in daytime and at night are discussed in Publication CIE 74-1988 "Roadsigns".

A retroreflector possesses the property of returning light incident to its surface in the direction of the source. At night, the driver of the vehicle is close to the light source - the vehicle headlights - and sees the retroreflector as a luminous surface. It is apparent that headlamps play an important role in the night-time visibility of retroreflectors since sign luminance is proportional to the headlamp output. This enhancement in night-time luminance results in a high contrast with the dark surround and provides the necessary improvement in visibility to make most traffic signs effective without the need for separate illumination.

Retroreflective materials are provided in sheet form, and occasionally as unit reflectors. Sheetings are available in a variety of colours for treating selected portions or all of the sign surface. Such materials are also provided in differing grades, corresponding to levels of retroreflective efficiency. The various grades of materials permit adapting specific signs to higher or lower relative luminance levels. Some materials are designed for maximising sign durability, while others are intended for short term usage. Unit reflectors may be used for delineation and sign lettering. The description and uses of these materials may be found in Publication CIE 72-1987, "Guide to the properties and uses of retroreflectors at night".

The various qualities of signing materials, differing sign manufacturing processes, and the selection of sign substrate materials, will all have an effect on the ultimate life of the sign. The exterior location of the sign exposes it to weathering stresses caused by such factors as the ultraviolet portion of sunlight, moisture, and high daytime/low night-time temperature cycling. Such stresses ultimately degrade the transparency, colour, and integrity of materials employed in retroreflective signs and thereby reduce their night-time visibility. The condition is easily verified during a night-time inspection. By inspection from a vehicle the night-time luminance of a new sign may be compared with the old. A side by side comparison at normal viewing distance will demonstrate the serious loss of visibility sustained from prolonged weathering. Between the state of a new unexposed retroreflective sign and one degraded by weathering, lies a gradual continuum of decreasing visibility. The cycle is highly variable, requiring from months to more than a decade to run its course. Examples of signs from new to seriously degraded are illustrated in Figure 2.1.

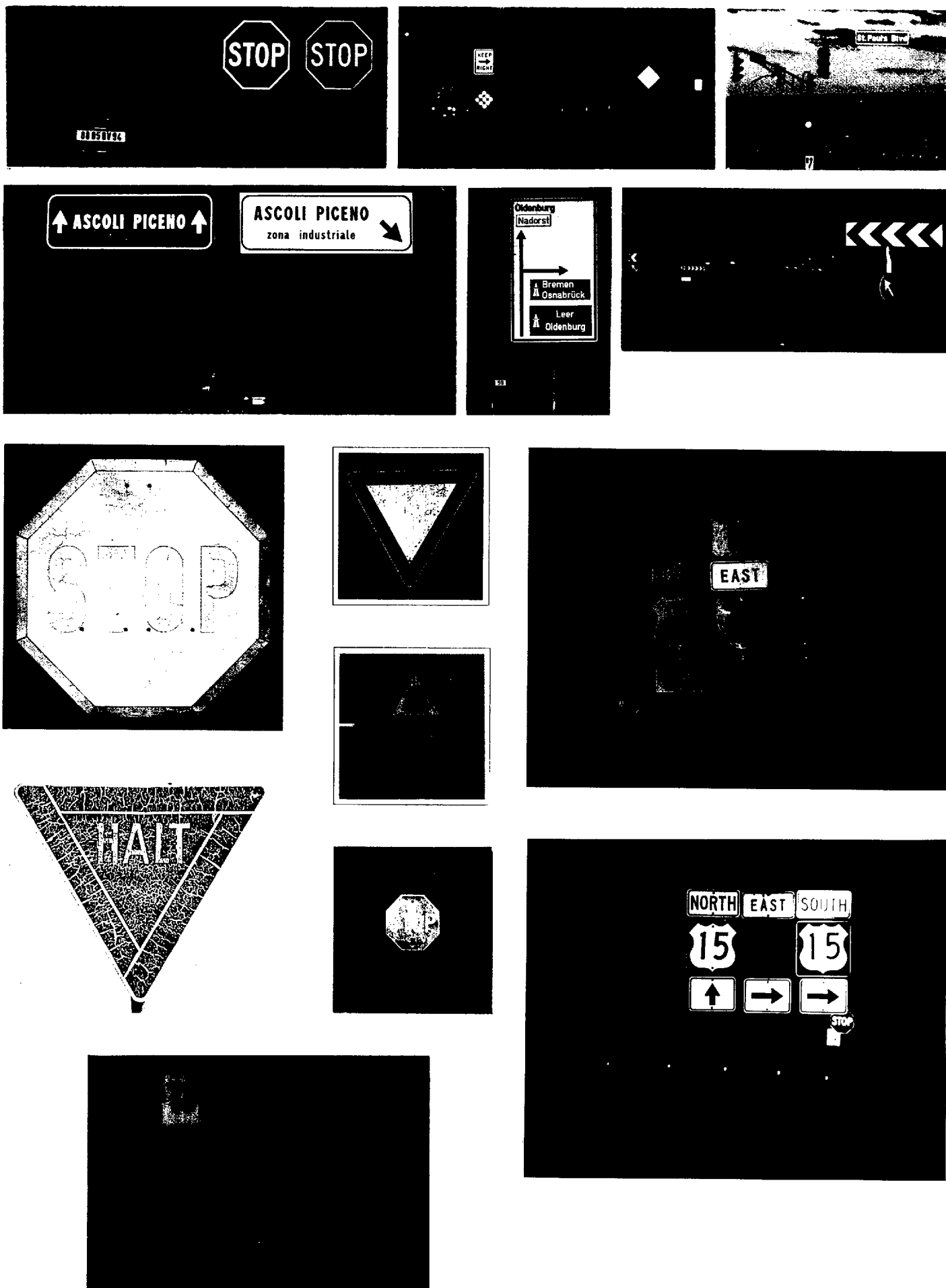


Figure 2.1 New and degraded signs.

2.1 Factors affecting retroreflective sign luminance

2.1.1 Sign luminance replacement factors

The development of a single level of retroreflectivity at which all signs could be replaced is a concept of appealing simplicity. At night, however, numerous operational and viewing circumstances will place differing demands on the driver, requiring separate consideration of a number of factors encountered in night-time driving. Further, as signs weather to a lower level of performance, a relatively more critical level of visibility is encountered in which the sign becomes less easily detected and less legible for an ever larger number of drivers. This condition becomes progressively worse, making the sign ineffective and, at some point, a candidate for replacement. The factors presented below show the dependence of night-time sign luminance on not only the retroreflective quality of the materials used, but also the colour of the sign, vehicle lighting, roadway alignment, and ultimately, the driver's perceptual process. These variables suggest a factor of safety be included to accommodate one or more combinations which may be present at any given location.

Factors Affecting Retroreflective Sign Luminance:

Entrance Angle	The angle of the sign plane relative to the illumination from the headlamp.
Observation Angle	The angular separation of the vehicle headlamps, the sign and the driver's eyes.
Colour	Colour is provided by filtering out part of the incident illuminance, reducing sign luminance.
Fog, Dew, Rain, Dirt	These factors tend to attenuate both the incident illuminance and the retroreflected luminance.
Weathering	Over time, weathering reduces the efficiency of the materials used in the retroreflective sheeting, requiring its eventual replacement.
Roadway Curvature, Roadway Width, Sign Position, Small Signs	These factors place the sign at varying distances and positions within the field of the headlamps affecting the resulting sign luminance.
Headlamp Beam Pattern	The unequal light distribution across the driver's visual field affects the sign luminance as does the varying quality and type of headlamps employed.
Headlamp Beam Usage	Headlamps have upper and lower beam patterns. The principal usage considered is the sign luminance developed by lower beams.
Headlamp Quality	Variation in headlamp quality causes an equivalent variation in retroreflective sign luminance.
Visual Acuity	Sign reading distance is shortened by loss of visual acuity.
Driver Age and Visual Status	Older drivers usually perform less well in evaluations of sign detection, identification and reading distance.

These factors are reviewed as they affect the luminance of the retroreflective sign and the driver's perception of it.

2.1.2 Geometric factors

The geometry of the sign position, vehicle lighting system and viewer position in the vehicle significantly affect the observed luminance of a retroreflective sign. Four angles are required for a complete description (Publication CIE 54-1982). Two angles are of primary interest.

2.1.2.1 Entrance angle

The entrance angle is primarily determined by the position of the sign at the road edge and the geometry of the approaching road alignment (see Fig. 2.2).

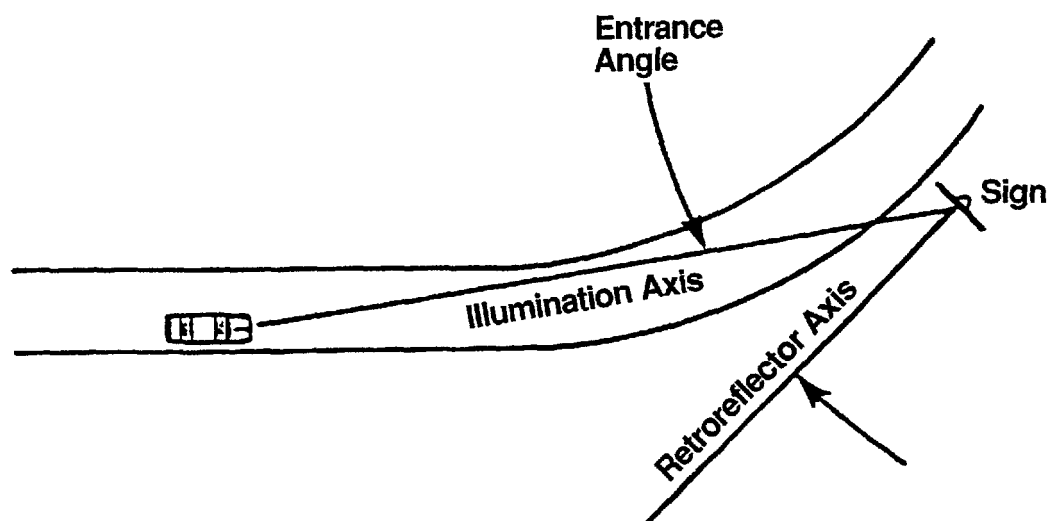


Figure 2.2 Entrance angle of retroreflective sign.

The entrance angle is the angle between the illumination axis and retroreflector axis (a perpendicular to the reference centre at the plane of the retroreflector). Signs or other retroreflective devices installed at an angle to oncoming traffic will display something less than the luminance experienced at near perpendicular. The luminance loss can be gauged from photometric data supplied by the manufacturer, or can be determined according to the standardised test method described in Publication CIE 54-1982. Luminance losses up to an entrance angle of approximately 15° are usually negligible and for some materials are not of major significance until 30° or more. The Griffith, Paniati and Hanley survey (1993) of entrance angles suggest that 5% of US signs or other retroreflective devices may be viewed at angles of 25° or more.

2.1.2.2 Observation angle

The observation angle is determined by the separation of the viewer from the vehicle headlighting system and is proportional to the distance to the sign (see Fig. 2.3).

The observation angles are the angles between the illumination axis and the observation axis. For a typical passenger vehicle, there are two observation angles determined by the driver eye height relative to the headlamp height, the lateral offset and set back to the driver with respect to the two headlamps, and the distance to the sign.

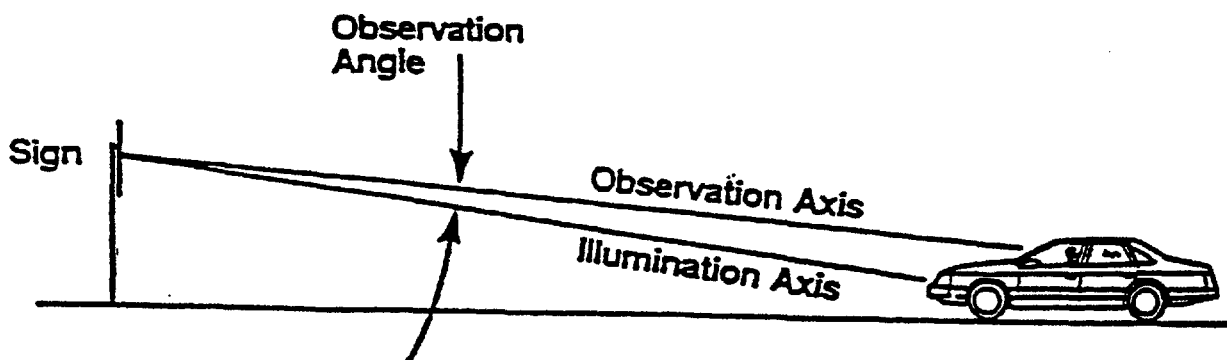


Figure 2.3 Observation angle of retroreflective sign.

The amount of light reflected from a retroreflective traffic sign decreases with an increase in the observation angle. As may be determined from Figure 2.3, reducing the vehicle to sign distance increases the observation angle. Replacement of the passenger car with a large truck will increase the observation angle. Because of the increased seated eye height of truck drivers, the actual observation angles are greater for them than they are for car drivers.

Sivak, Flannagan and Gellatly (1991) evaluated the relative amount of light reaching drivers of different types of vehicles. Their analysis considered three sign locations and two viewing distances judged appropriate for high speed roadways, 152 m (500 feet) (typical of a sign-legibility distance), and 305 m (1.000 feet) (typical of a sign-detection distance). The analysis considered both the differential amount of illumination impinging on the signs from headlamps of trucks and cars, as well as the differential amount of the light reflected from the signs in the direction of truck drivers and car drivers.

The results are that for the viewing distance of 152 m, the amount of light reaching a truck driver can be as low as 25% of the light reaching a car driver; the corresponding percentages for the viewing distance of 305 m are as low as 68%. These reductions were then related to the expected effects on sign legibility and detection. The results imply that the increased eye height of truck drivers could have a major effect, greatly decreasing the legibility of retroreflective traffic signs, and modestly reducing their detection distance.

Krochmann and Terstiege (1990) made similar investigations of luminance of retroreflecting materials with different colours for a typical light distribution of German headlamps for a typical headlamp height of 0,63 m and height of the car driver's eye of 1,17 m.

2.2 Ideal conditions

The ideal viewing condition for the retroreflective road sign is one which presents the sign under the most favourable viewing circumstance. Such a circumstance would present a sign that would be new, clean, and, to assure optimum luminance, white in colour. The most favoured position places the sign in the area of greatest headlamp illuminance at the near pavement edge and close to the road surface or just over the crest of a vertical curve. The most satisfactory approach should enable discovery of the sign close to the point of visual focus. The driver will be best adapted visually if the foreground is devoid of glare sources and visual noise. The driver most likely to detect and read the sign first will be young and of normal night-time visual acuity.

It is apparent that two general ideas have been invoked: one is geometric - a section of roadway with a sign of the most luminous colour favourably aligned for the headlamp aim. The other is psychometric - a driver, with eyes adapted to a mesopic level of luminance, and with only the sign in view. Both are required for the ideal condition. One condition assures an unimpaired level of retroreflective sign luminance, the other assures unimpaired perception by the driver. It will be seen that modification of either has the effect of lowering sign luminance or the perception of it.

2.3 Sign factors

2.3.1 Retroreflective signing material types

Retroreflective materials are available in various grades, generally comprising the following types: enclosed and encapsulated lens sheetings employ glass beads designed to focus and reflect the incident light from a metallic reflector coat. Microprismatic sheetings employ cube corners arrayed to reflect light. Each type is provided in a range of colours useful for traffic signing and possess varying degrees of retroreflective efficiency and durability.

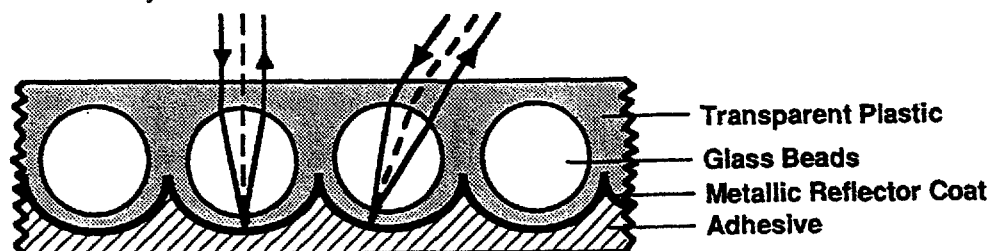


Figure 2.4 Enclosed lens sheeting.

Enclosed lens sheeting consists of a layer of transparent plastic of appropriate colour in which glass beads are embedded. A metallic reflector coating is provided behind the beads followed by an adhesive layer to bond the sheeting to the sign substrate (see Fig. 2.4).

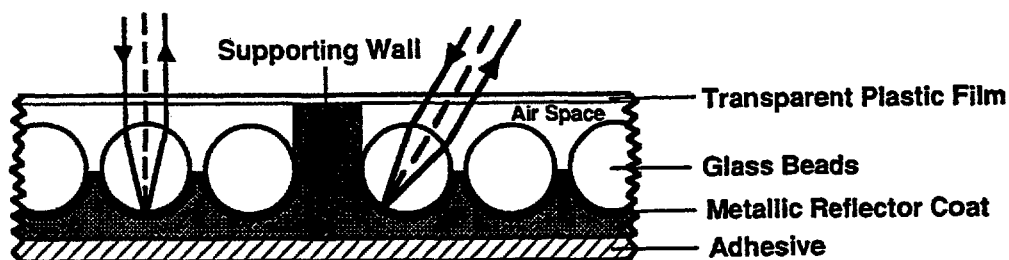


Figure 2.5 Encapsulated lens sheeting.

Encapsulated lens sheeting consists of a transparent plastic film of appropriate colour supported above the beads by walls leaving a sealed compartment. The back of the beads are provided with a metallic reflector coating followed by an adhesive layer to bond the sheeting to the sign substrate (see Fig. 2.5).

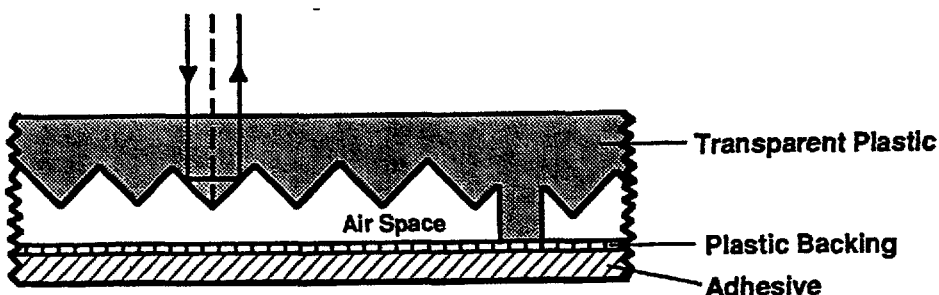


Figure 2.6 Prismatic sheeting.

Prismatic sheeting consists of a transparent plastic of appropriate colour having cube corners moulded on the underside. An air space is provided by sealing a plastic backing at intervals across the back followed by an adhesive layer to bond the sheet to the sign substrate (see Fig. 2.6).

The sign luminance provided by the three types of materials have been estimated by Woltman and Szczech (1988), and are represented in Figure 2.7 for Economic Commission for Europe (ECE) and USA low beam headlamps. The sign position is on the near shoulder 4,3 metres beyond the pavement edge at an elevation of 2,1 metres. The vehicle centreline is 1,8 metres from the near pavement edge, centred within a 3,66 metro lane. The figures were derived from the headlamp distributions provided in Tables 7.4 and 7.5.

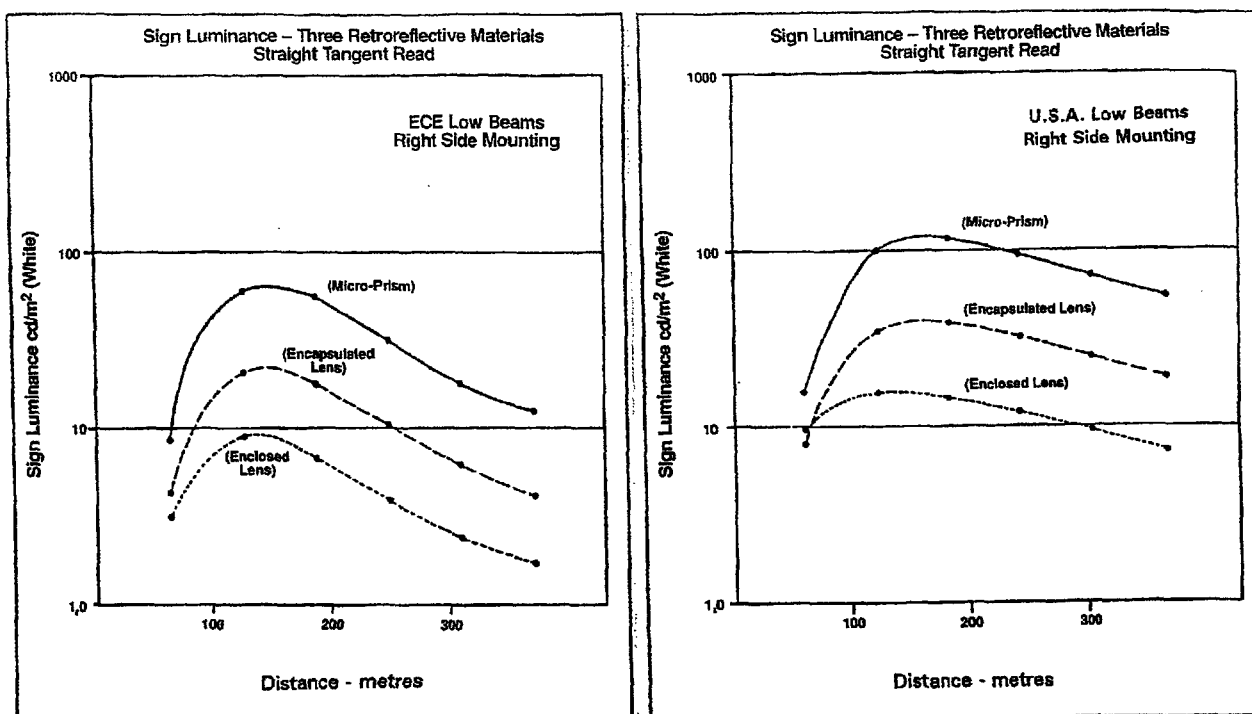


Figure 2.7 Sign luminance estimates * for three retroreflective materials.
White colour, USA, and ECE low beams, shoulder position.

*Sign luminance estimates do not include a reduction for windshield absorption. Windshield absorption reduces the values shown. See 2.5.4.

The differences in luminance values from Figures 2.7 and 2.8 are the result of differing headlamp illuminances and are not atypical of headlamp outputs encountered. Sign position in relation to the headlamps may also be at variance.

2.3.2 Sign colour

The night-time colour of retroreflective materials is produced by colorants in the material filtering the headlamp luminous flux; thus the luminance of colours are a fraction of the luminance of the white material. From Woltman and Szczech (1988) and from DIN specifications, these fractions are as shown in Table 2.1.

Under the same conditions of illumination and viewing, luminance ratios and R' ratios are the same for retroreflective sheeting colours as a percent of white sheeting. Values are typical for incandescent lamps of white colour corresponding to CIE standard illuminant A, and will vary somewhat for other types of lamps.

Table 2.1: Ratio (Percent) of Colour to White (R' of Colour Divided by R' of White)

Colour	Woltman/Szczzech (Encapsulated & Enclosed Lens)	Type 1 according to DIN 67520-2 Enclosed Lens	Type 2 according to DIN 67520-2 Encapsulated Lens
White	100	100	100
Yellow	61 to 76	58 to 75	68 to 75
Orange	33 to 42	25 to 38	34 to 38
Red	17 to 30	17 to 20	14 to 20
Green	13 to 19	12	15
Blue	7 to 10	5	5 to 8
Brown	2 to 5	1 to 2	—

* R' is the coefficient of retroreflection measured in $\text{cd} \cdot \text{lx}^{-1} \cdot \text{m}^{-2}$.¹⁾

Figure 2.8 (IRF, 1991) shows the luminance values for Class II (encapsulated lens) and Class I (enclosed lens) retroreflective materials for two colours (white and blue) in relation to observation distance.

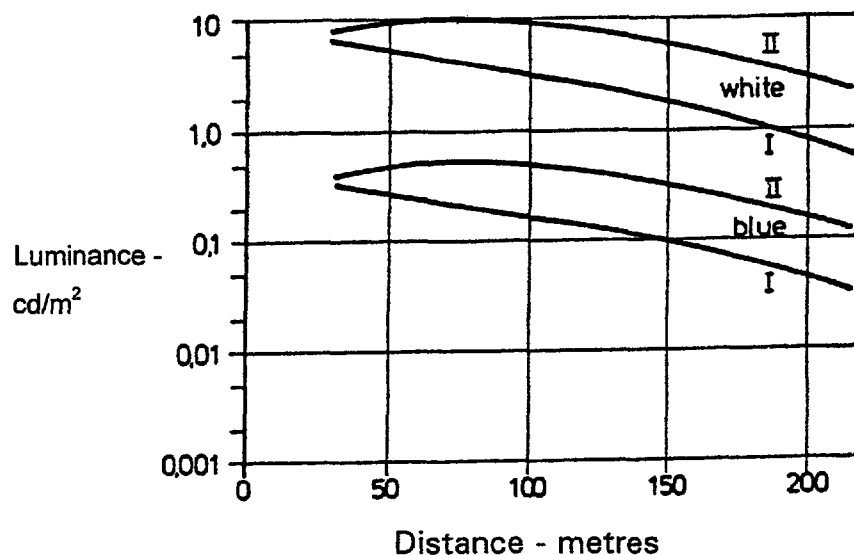


Figure 2.8 Luminance of white and blue retroreflective materials shoulder mounted, when illuminated by an ECE low beam headlamp system at different distances.

Although the lower luminance values provided by colours may suggest shorter night-time detection distances, a heterochromatic effect is also present. This has been investigated by Olson (1988), for retroreflective signs, but the allowance for the apparent enhancement by colours has not been evaluated with great rigor. The colours providing enhancement; orange, red, green and blue, provided visibility distances beyond that predicted for their coefficient of retroreflection. This effect has been observed in other tests of colour response. Colours for which no heterochromatic effect were observed were white and yellow.

A sign detection model developed by Forbes (1980) estimates the distance at which a sign will be seen. The size relationship provides that a doubling of sign size doubles the expected detection distance. For legibility Mace and Garvey (1994) have found that this assumption is less than proportional for large letters read at distances of over 200 metres.

¹⁾ In this document we will usually use a slash (/), when an expression contains one symbol as nominator and one symbol as denominator, but will use negative exponents if the expression contains more than two symbols.

2.3.3 *Fog, dew, and rain*

Fog has the effect of absorbing and scattering the luminous flux before the headlamp flux reaches the sign. The retroreflective materials therefore receive less illuminance than under clear conditions. The retroreflected light must return through the same atmosphere where absorption and scattering occurs a second time. The diminution of sign luminance is therefore the second power of atmospheric transmittance by comparison to an illuminated sign. For this reason, fog prone locales may warrant illumination of critical signs, larger than normal sign size, more efficient retroreflective signing materials, or advance warning signs. (See also 2.3.5.)

The apparent luminance of a retroreflective sign may be reduced by the refraction and scattering of the incident illumination caused by the formation of dew or, at subfreezing temperatures, frost. Two studies by Woltman (1965) and by Hutchinson and Pullen (1978) identify the most dew resistant materials and existent means of control.

Rainfall alters the specular reflection of the road surface, reflecting some of the lower beam output up toward the overhead signs. The specularity of the road surface is highly variable as described in Publication CIE 74-1988. Stream traffic positions other cars ahead of and behind drivers, resulting in additional contributions to sign luminance. Nevertheless, the single vehicle on the dry, low reflectance road surface using lower beams should be assumed in estimations of sign luminance or retroreflectivity requirements.

2.3.4 *Dirt*

Dirt collects on signs by splash and spray from passing vehicles and from aerosols deposited at other times. Although rain washes signs, seasonal variation in dirt collection is most apparent in winter months when freeze/thaw cycles provide the necessary mechanism. Several studies of retroreflection loss due to dirt have been published. Davis and Fitzpatrick (1954) provide the relationship of sign retroreflectivity loss to distance from the wheel track area, while Rumar (1974) provides information on the loss of illuminance from the headlamps due to dirt sprayed from leading and passing cars onto the lens surface. A second study by Rumar and Ost (1974) report a 70% decrement in sign legibility as the result of extreme soil collection on the sign face compared to a clean road sign.

Jenkins and Gennaoui (1992) report a reduction in retroreflection of from 10 to 15 percent from dirt on sign faces. In normal usage rain often tends to wash signs clean. Sign washing may be a necessity in construction work zone areas. Simple cleaning with water just prior to field photometric measurements resulted in an increase of 11,9% for enclosed lens sheetings, and 7,8% for encapsulated lens sheetings for 336 and 251 signs of each respective type in the study by Black, McGee, Hussain and Rennilson (1991).

2.3.5 *Weathering*

Exterior placement of signs exposes the retroreflective surface to sunlight and ultraviolet radiation, rain and dew, and the temperature cycling from day to night and summer weather to winter. These exposure conditions result in weathering stresses which degrade the transparency of the plastic resins employed in these materials and fade the pigments of colours used in the design of the sign. The rate of failure is dependent on several factors: 1) The locale in which the sign is exposed. Generally equatorial latitudes produce a more rapid rate of decay than temperate or polar latitudes. 2) Various materials employed for signing generally have different ageing characteristics (e.g. enclosed lens materials have been found to have a shorter life than encapsulated lens). 3) Those signs printed with transparent inks will have different fading rates than retroreflective sheetings having the same colour incorporated within them during manufacture.

The studies on the ageing of road signs indicate that the government requirements pertaining to signs following periods of exposure are often not met. Thus Terstiege (1983) has stated that after a period of eight years, half of retroreflecting signs do not reach the values specified in DIN 6171; after 12 years, 100% failed to meet this requirement. The scientific basis for this is provided by the study "Changes in Visibility Characteristics and the Service Life of Enclosed Lens Retroreflecting Road Signs as Specified in DIN 6171-1 (July 1979)". In this report (see Woltman [1987]), Terstiege comes to the conclusion that:

"Type 1* [enclosed lens] retroreflecting road signs with reflected colours as specified in DIN 6171-1 (July 1979) start to become defective once they have been in use in the open air for four years. Deterioration is then at an almost constant rate of 13% per year, in relation to the total number of road signs in use. After eight years, the failure rate is likely to be 50% (deterioration at 26% per year) and after 12 years, this is likely to be almost 100%. The main effects of this deterioration are the failure to meet the requirements for the minimum coefficient of retroreflection, R' , (at 0,33 deg obs./5 deg ent.) for type 1* for reflected colours white and yellow and the migration of the chromaticity from the operational condition in the case of reflected colour red as specified in DIN 6171-1 (July 1979)."

* according to DIN 67520-2

When plotting the coefficient of retroreflection R' for the white retroreflective materials on signs (mean values) in relation with their age, Figure 2.9, the IRF (1991) compares the results with the minimum legal values set out for new materials as required in several European countries and by CIE.

Line A represents the regression line for these mean values; the hatched borders 1 and 2 represent the minimum legal requirements in force in Germany (line 1) and France, UK and the CIE (line 2). The two dotted border lines B illustrate the area where with a probability of 95% all the mean values are located.

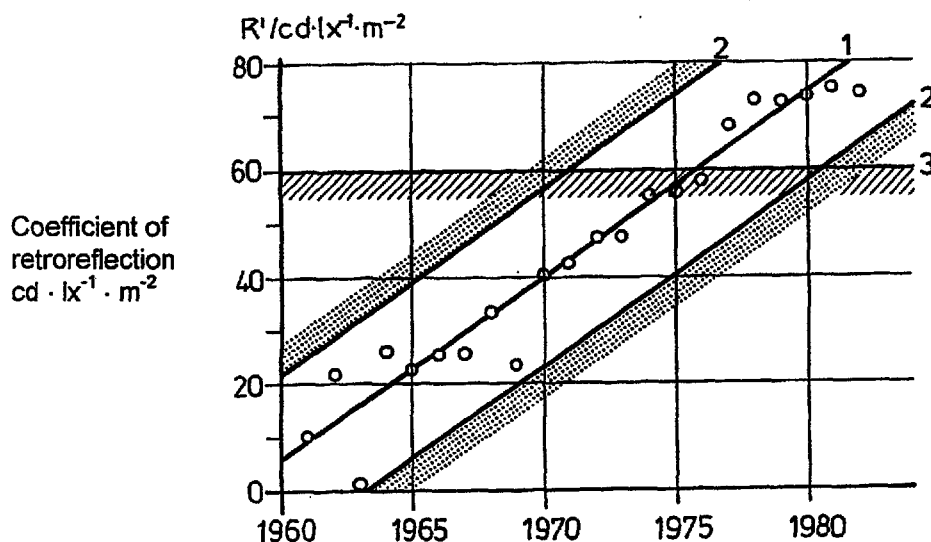


Figure 2.9 Coefficient of retroreflection for white materials type I according to DIN 67520-2 (enclosed lens) of different age. Shown is the year of manufacturing, investigation was done in 1983.

- | | | | |
|----|---------------------------------|----|--|
| 1: | regression line for the results | 3: | minimum value (for example in Germany) |
| 2: | boundary for a 95% probability | | |

The results of the investigation made in 1983 have been confirmed in the subsequent follow-up investigations.

The results of road sign surveys carried out by the Industrieverband Verkehrszeichen e.V. (Industrial Association for Road Signs) in association with the appropriate authorities give an indication of the number of road signs that are more than 10 years old. According to these, some 42% of road signs are over 10 years old out of an estimated total of 10 to 15 million warning, instructive and directional signs on West German roads.

From a field survey of South African signs, Sator (1989) reports many signs of Class 1 sheeting, (enclosed lens) had a useful life of 10 years. He reports the major problem as the fading of red screen printed signs of both Class 1 (enclosed lens) and Class 3 (encapsulated lens) sheeting. The survey measured the retroreflectivity of 697 signs, of which 374 were dated at time of manufacture.

2.3.5.1 Weathering performance, Australia

In a study intended to determine retroreflectivity values for signs at their terminal life, Jenkins and Gennaoui (1992), conducted a survey of 2 660 Australian retroreflective traffic signs. The signs were

classified as regulatory, warning or guide signs, the environment was classified as residential, industrial or beachside, and the signs were facing either north or south.

For these conditions the reported life performance data (Coefficient of retroreflection, R') of the sign material can be represented by a series of linear regression equations:

for Class 1 (encapsulated lens) white sheeting

$$R' = 294 - 4,05 \times \text{Age in years} \quad (2.1)$$

Class 2 (enclosed lens) white sheeting

$$R' = 116 - 5,62 \times \text{Age in years} \quad (2.2)$$

Class 2 yellow sheeting

$$R' = 96 - 5,07 \times \text{Age in years} \quad (2.3)$$

Class 1 white screen-printed red

$$R' = 16 + 3,1 \times \text{Age in years} \quad (2.4)$$

Class 2 white screen-printed red

(no one equation will do)

Class 1 green sheeting

(too few samples)

Class 2 green sheeting

$$R' = 22 - 1,0 \times \text{Age in years} \quad (2.5)$$

Little difference was found for the rate of degradation of sheeting facing either north or south. However, analysis of data from the signs in the tropical north shows a much faster degradation than the average for Australia as a whole. This result shows that UV exposure does have a major effect on sign degradation but the difference in exposure of north or south facing signs is not statistically significant. The type of environment does have a significant effect on the rate of sign degradation with the industrial area having the greatest adverse effect.

The data show that both classes of material have good durability. The white encapsulated lens sheeting falls to 80% of its retroreflectivity after about 14 years, and enclosed lens sheeting falls to 50% after 10 years for white, yellow and green. The red screen-printed background is quite different from the other colours. The encapsulated lens white sheeting screened red loses colour and lightens as it degraded so that the retroreflectivity increases with time. The enclosed lens white sheeting screened red is affected strongly by the type of environment it is in.

2.3.5.2 Weathering performance, United States

Black et al (1991), in an examination of the retroreflectivity of 6 275 traffic signs across the USA, developed equations describing the deterioration of retroreflectivity. The equations become the basis for the USA FHWA's Retroreflectivity Service Life Model. With the ability to predict in-service retroreflectivity and with the establishment of minimum retroreflectivity standards, specific signs could be highlighted in a computer inventory for inspection and replacement in a consistent, efficient and cost effective manner.

Although there was considerable variation in data, regression equations were developed by sheeting colour and type. They represent average durabilities of signs from the survey.

White enclosed lens sheeting

$$R' = 103,085 - 5,451(\text{age}) + 0,002(\text{deg days}) + 0,178(\text{precip}) + 0,002(\text{elev}). \quad (2.6)$$

White encapsulated lens sheeting

$$R' = 304,089 - 4,815(\text{age}) + 0,002(\text{deg days}) + 0,06(\text{precip}) + 0,001(\text{elev}). \quad (2.7)$$

Yellow enclosed lens sheeting

$$R' = 78,794 - 3,906(\text{age}) + 0,002(\text{deg days}) + 0,115(\text{precip}) + 0,002(\text{elev}). \quad (2.8)$$