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VISUAL ASPECTS OF ROAD MARKINGS

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Foreword

During its meeting in April 1981, CIE Technical Committee 1.6, Visual Signalling, decided to initiate a coordination of work in the field of road markings in a subcommittee of TC 1.6.

Before that time road markings were also treated from different specific points of view in the Technical Committees 2.3 (Materials), 4.6 (Road Lighting) and 4.7 (Automobile Lighting). In June 1981 the Action Committee of CIE approved the suggestion of TC 1.6.

In October 1981 the first meeting of the new Subcommittee was held with members recruited out of the four Technical Committees. Task for the committee – now TC 4-04 Road Markings in Division 4 Lighting and Signalling for Transport – was to draft a Technical Report on "Visual aspects of road markings" which should serve as basis for an International Standard.

First drafts of the 5 chapters were presented during an International Symposium held in Paris in May 2-3, 1983 under the patronage of CIE, PRI and PIARC. On this basis the Technical Committee 4-04 has prepared this report in the following years.

Vorwort

Während einer Sitzung des CIE-Technischen Komitees 1.6 "Verkehrssignale" im April 1981 wurde beschlossen, die Arbeiten auf dem Gebiet der Fahrbahnmarkierungen in einem Unterkomitee des TC 1.6 zu koordinieren.

Vor dieser Zeit wurden Fahrbahnmarkierungen unter den verschiedensten Gesichtspunkten in den Technischen Komitees 2.3 (Baustoffe), 4.6 (Straßenbeleuchtung) und 4.7 (Kraftfahrzeugbeleuchtung) behandelt. Im Juni 1981 stimmte das CIE-Aktionskomitee den Vorschlägen des TC 1.6 zu.

Im Oktober 1981 fand die erste Sitzung des neuen Unterkomitees statt, dessen Mitarbeiter sich aus denen der o.g. Technischen Komitees zusammensetzten. Aufgabe dieses Komitees – nummehr TC 4-04 "Fahrbahnmarkierungen" in der Division 4 "Beleuchtung und Signale für den Verkehr" – war die Erarbeitung eines Technischen Berichtes über "Visual aspects of road markings", welcher als Grundlage für internationale Standards dienen soll.

Die ersten Entwürfe der fünf Kapitel wurden in Paris am 2. und 3. Mai 1983 auf einem Internationalen Symposium vorgetragen, das unter der Schirmherrschaft der CIE, PRI und PIARC stattfand. Auf dieser Grundlage hat das TC 4-04 den vorliegenden technischen Bericht in den folgenden Jahren erarbeitet.

Avant-Propos

Au cours de sa réunion du mois d'avril 1981, le Comité Technique TC 1.6 – Signalisation Visuelle de la CIE, a pris l'initiative de confier à un sous-comité la coordination des travaux dans le domaine des marquages routiers.

Avant cette date, les problèmes relatifs aux marquages routiers étaient traités en fonction de leurs points de vue spécifiques par les Comités Techniques 2.3 (Matériaux), 4.6 (Eclairage des voies publiques) et 4.7 (Dispositifs d'éclairage des automobiles). En juin 1981, le Comité d'Action de la CIE a approuvé la décision du Comité TC 1.6.

En octobre 1981 fut tenue la première réunion de ce nouveau sous-comité, avec la participation de membres recrutés dans les 4 Comités Techniques.

La tâche de ce sous-comité, actuellement désigné comme la comité TC 4-04 "Marquages routiers" de la division 4 Eclairage et signalisation pour les transports, était de préparer un Rapport Technique sur les "Aspects visuels des marquages routiers", en vue de servir de base à une norme internationale.

Les premiers projets pour les 5 chapitres furent présentés lors d'un symposium international tenu à Paris les 2 et 3 mai 1983 sous le patronage de la CIE, de la PRI et de l'AIPCR. C'est sur cette base qu'au cours des années suivantes, le Comité Technique 4-04 a préparé le présent rapport.

Any mention of organisations or products does not imply endorsement by the CIE. Whilst every care has been taken in the compilation of any lists, up to the time of going to press, these may not be comprehensive.

Toute mention d'organisme ou de produit n'implique pas une préférence de la CIE. Malgré le soin apporté à la compilation de tous les documents jusqu'à la mise sous presse, ce travail ne saurait être exhaustif.

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Summary

Purpose of this report of TC 4-04 is to provide the information necessary for understanding future standards for light-technical properties of road markings in road traffic.

The report does not deal with traffic control rules for road traffic. The report is segmented into 5 chapters:

The *first chapter* deals with the principles of information-transfer by road markings. These are of high importance today for the optical guidance of traffic. Therefore, road markings have to satisfy functional requirements especially with regard to their light technical properties.

The *second chapter* describes the requirements for road markings and raised pavement markers for driving by day and night. A detailed mathematical treatment deals with the distances from which road markings are visible.

The *third chapter* describes the importance of glass beads for nighttime visibility and their application in road markings. The behaviour of beaded paints under traffic wear is reported.

The *fourth chapter* reports on products and materials used for markings including center- or edgelines. The influence of the road surface and its temperature changes on daytime visibility is reported.

Chapter five deals with the photometry and colorimetry of the markings. Definitions for the various terms are given and methods of measurement in the laboratory as well as on the road are described.

Two different geometries for measurements are in use and described. It was possible to develop a mathematical transformation between the angular coordinate system of road lighting and the angular coordinate system of retroreflection.

This work revealed that most retroreflectometers used today are working with simplified geometries which do not allow direct conclusions on the real parameters.

Development of portable retroreflectometers for satisfactory measurements on profiled road markings is needed. Also the development of an instrument to measure daytime visibility of road markings under diffuse illumination and grazing direction of observation is desirable.

Zusammenfassung

Zweck dieses Berichtes des TC 4-04 ist, die notwendigen Informationen zu vermitteln, die für zukünftige Standards der lichttechnischen Eigenschaften von Fahrbahnmarkierungen für den Straßenverkehr benötigt werden.

Das *erste Kapitel* beschreibt die Prinzipien der Informationsübertragung durch Fahrbahnmarkierungen. Diese sind heute für die optische Führung des Verkehrs außerordentlich wichtig. Deswegen haben Fahrbahnmarkierungen durch lichttechnische Eigenschaften bestimmten funktionellen Anforderungen zu genügen.

Das *zweite Kapitel* beschreibt die Anforderungen für Fahrbahnmarkierungen und Markierungen mit Reflektoren für das Fahren bei Tag und Nacht. Eine detaillierte mathematische Abhandlung beschäftigt sich mit der Erkennbarkeitsentfernung für die Markierungen.

Das *dritte Kapitel* behandelt die Bedeutung der Glasperlen für die Nachtsichtbarkeit und ihre Anwendung in Fahrbahnmarkierungen. Über das Verhalten von Farben mit Glasperlen unter Verkehrsbelastung wird berichtet.

Das *vierte Kapitel* behandelt Produkte und Materialien, welche für Markierungen einschließlich von Mittel- und Randmarkierungen verwendet werden. Der Einfluß der Fahrbahnoberfläche und ihre Temperaturänderungen auf die Tagessichtbarkeit wird berichtet.

Kapitel fünf behandelt die Photometrie und Kolorimetrie der Fahrbahnmarkierungen. Definitionen der verschiedenen Meßgrößen werden angeführt und Methoden zu ihrer Messung, sowohl im Labor als auch auf der Fahrbahn, beschrieben.

Zwei verschiedene Geometrien für heute übliche Messungen werden aufgeführt. Es war möglich, eine mathematische Transformation zwischen der Geometrie für die öffentliche Beleuchtung und der Geometrie zur Messung der Retroreflexion anzugeben.

Die Transformation zeigt zudem, daß viele Retroreflektometer, welche heute mit vereinfachten Geometrien arbeiten, keine direkten Schlüsse auf die realen Verhältnisse zulassen.

Die Entwicklung tragbarer Retroreflektometer für zufriedenstellende Messungen an profilierten Fahrbahnmarkierungen ist nötig. Auch die Entwicklung von Instrumenten zur Messung der Tagessichtbarkeit von Fahrbahnmarkierungen unter diffuser Beleuchtung und streifender Beobachtungsrichtung ist wünschenswert.

Resume

Le but de ce rapport du T.C. 4-04 est de fournir les informations nécessaires pour la compréhension des futures normes concernant les propriétés optiques des marquages routiers.

Le rapport ne traite pas des règles d'implantation des marquages.

Le rapport comporte cinq chapitres:

Le premier chapitre traite des principes du transfert d'informations par les marquages routiers. Celui-ci est aujourd'hui de grande importance pour le guidage optique de la circulation. Ainsi, les marquages routiers doivent répondre à des exigences fonctionnelles, en particulier pour les propriétés optiques des marquages.

Le second chapitre décrit les exigences pour les marquages routiers et les plots pour la conduite de jour et de nuit. Un modèle mathématique détaillé fournit les distances auxquelles les marquages routiers sont visibles.

Le troisième chapitre décrit l'importance des billes de verre et de leur application pour la visibilité de nuit des marquages routiers. On étudie le comportement sous circulation des peintures avec billes de verre.

Le quatrième chapitre traite des produits et matériaux utilisés pour les marquages, qu'il s'agisse de bandes axiales ou de bandes de rive. On étudie l'influence de la surface de la route et des changements de température sur la visibilité de jour.

Le cinquième chapitre traite de la photométrie et de la colorimétrie des marquages. Des définitions sont données ainsi que les méthodes de mesure utilisables tant en laboratoire que sur route. Deux géométries différentes en usage pour les mesures sont décrites et il a été possible de développer une transformation mathématique entre le système d'angles utilisé pour l'éclairage public et celui préconisé pour la rétroreflexion. Cet effort a montré que les rétroreflektomètres couramment utilisés travaillent avec des géométries simplifiées qui ne permettent pas d'obtenir des conclusions directes sur les paramètres réels. Le développement de rétroreflektomètres portables pour la mesure des marquages profilés est nécessaire ainsi que celui d'un instrument pour mesurer la visibilité de jour des marquages routiers sous éclairage diffus avec observation sous un angle rasant.

1 Principles of information transfer by road markings

1.1 Introduction

The social pattern within industrialized countries is based on a high degree of specialisation and of local separation of activities. As a consequence the pattern can only continue to exist if a very large amount of transport takes place – transport of information, of persons, of goods.

Road transport has a special place in this. The special place is the result of the following:

- most of the traffic participants are "lay-men", i.e. not professionally trained (unlike in air or rail traffic)
- traffic control is effected to a large extent by the traffic participant making decisions on the basis of information (nearly exclusively visual information) they collect on the spot
- the road is used at the same time and place by a variety of vehicles differing very much in their characteristics and performance (bicycles, cars, etc. and pedestrians).

Various means are required in order to make the transportation possible. These means include roads, vehicles, traffic rules, etc., in which road markings have a specific and important function.

The function can be derived from the driving task of the individual vehicle operators. Although, as regards road safety, all road users – notably pedestrians – are equally important, the following concentrates on motor vehicles.

The driving task can be described as follows, taking into account that road vehicles may move in two directions: lengthwise and crosswise. These two modes are indicated by x and y respectively. In principle all values of x and y , and of the (higher) derivatives may be selected. In practice, however, this freedom is very severely restricted by the characteristics of the road, the vehicle, the driver and other traffic. Also the speed is monitored to large extent by "higher" aspects of the travel, such as the purpose and the motivation of the trip. We will restrict ourselves to the "lower" aspects of the driving task: The manoeuvre-behaviour.

Two aspects of this manoeuvre-behaviour are to be discerned: normal driving and coping with emergencies. As rather different aspects of the human operator are involved, it seems justified to introduce the following (simplified) model.

1. Driving behaviour on the manoeuvre-level can be divided into: normal driving (the basic task) and avoiding collisions (the coping task).
2. An emergency is frequently caused by operator failure to perform the basic task adequately, that is crossing lane or edgelines, inadvertently overdriving headlights, driving with an impairment, etc. Accidents may also be described in terms of failing to cope with the emergencies.
3. Vehicle manoeuvres are restricted to selections of speed and lateral position and variations in these.

This simplified model leads to the following results, that in fact are the back bone of the functional requirements for all sorts of traffic means and measures, including road markings.

- A. The basic task is essentially a control task, consisting of the selection of the speed and lateral position in accordance with the environmental and other restrictions and the trip selection and motivation.
- B. The coping task is the selection of new values of speed and lateral position in such a way that the emergency situation will not result in a serious conflict or a collision. (Obviously this involves higher derivatives of x and y).

It should be noted that according to this model the emergency *always* is unexpected, and *always* means a deviation of the originally planned route.

Driving a car requires a large amount of information from the environment. This implies certain objects from which information of some kind is needed, either *signals* or *cues*.

The object itself or some characteristics of it (in this case described as "signals") is set up on purpose in order to convey a message of a kind to the observer. The message usually is directly connected to the driving task and particularly to some kind of required response, such as: stop, or keep right. According to this description "road signs" should be classified as "*signals*".

Another type of information is conveyed by objects within the field of view that are self-explanatory. Such objects are called "*cues*".

The information they convey is implicit and non-conventional. As an example, the curvature and layout of a bend will indicate to the (experienced) driver the appropriate speed to round that bend.

The distinction between signals and cues is not an absolute one. One may define an intermediate form: "*markings*". Markings may be considered as signals with a very simple message (such as "presence" and nothing more) or as cues that are placed on purpose. If a row of dots or cats-eyes on the road has no particular coded message, in the legal sense, then it marks clearly the centre of the carriageway.

At day under normal weather conditions, the cue-objects, being mostly self-explanatory, offer little problems as regards their visibility, as long as they are properly placed, large enough, and show a distinct contrast (both as regards colour and luminance) with their direct background.

At night, or under situations of reduced visibility (fog, snow, heavy rain) most non-luminous objects are not visible any more. Some countermeasures are needed in order to maintain the information transfer. At night this is generally realised by shining light directly onto these objects, trusting that they still will be self-explanatory. In other words, the major difference between day and night is that in daylight there are many cues for driver visual guidance. Therefore, individual cues need not be very strong. At night, most of the natural cues – road edges, embankments, crops, guardrail, etc. – are well below visual threshold and disappear. Therefore, the driver is much more reliant on the pavement marking system for path guidance cues. Retroreflective performance of stripes is far more important than the daytime appearance criteria often used to evaluate stripes (see also Chapter 2).

This chapter is a brief summary of a very large field of experience. In drafting, the results of the CIE symposium on "Visual aspects of road markings" held in Paris on 2–4 May 1983 have been taken into full account. A more complete treatment is available in the literature; see e.g. [1 - 19] and more particularly the excellent survey of present materials prepared by the New York State Department of Transportation [20].

1.2 Vehicle operation

Driving a car can be described in terms of information processing [21 - 23] and of decision making [24 - 29].

The actual handling of the vehicle is, as we have seen, often called a control task. In fact, there are two, because the road vehicle is essentially a vehicle with two independent directions of movement; they relate to the control of the crosswise and the lengthwise position.

The first can be described as keeping the position within the driving lane as nearly constant as possible. In fact, it seems that the angular velocity of the aiming angle, and the lateral velocity are the best criteria for this [30]. It may be added here that McLean & Hoffmann [31] prefer the direct control of lateral error.

The second has to do with the forward movement, and will most probably be described by the task of keeping the forward velocity at a safe level consistent with conditions.

The visual requirements for these relatively simple tasks are rather simple as well. In order to maintain a lateral position close enough to the desired position, only small steering corrections are required. For this, it is sufficient that the lane markers are visible, particularly at short distance. At day, and also at night under dry conditions, this can easily be achieved by retroreflective road-marking materials. Problems, however, can be quite serious when the road is wet.

A further general analysis of the vehicle handling aspects is given by Blaauw [32], Blaauw & Padmos [33, 34], and Veling [35].

Specifications for road markings and their requirements are discussed in [11, 36].

1.3 Functional requirements of road markings

As a preliminary some quotations are given from the comprehensive OECD report [5]:

"A clear and precise system of horizontal signing in the form of road markings together with lateral delineators (posts) serve a special purpose by facilitating driver guidance, thus improving traffic flow and contributing to driving comfort and safety."

"Although investigations have shown that the driver's eye is much more attentive to markings on the roadway than to lateral signs [37, 38], such as delineators, these nevertheless have the advantage of remaining visible under conditions such as very dense traffic, heavy rain or snow. Lane markings on the roadway help drivers to keep within lanes. Edge markings and delineators make the limits of the roadway show up more clearly and provide optical guidance. These types of longitudinal markings also provide valuable guidance for driving at night or in fog" (see also [1, 7, 39 - 44]).

A general awareness that uniformity of use of marking devices was desirable, especially because their geometric form and colour constitute messages to drivers, gradually led to a set of regulations specifying shape and colour of marking devices. International standardisation also proceeded and has led to the "Convention of Road Signs and Signals, opened for signature in Vienna on 8th November, 1968" (Vienna Convention). In Europe, more detailed regulations are given in the "Protocol on Road Markings, Additional to the European Agreement Supplementing the Convention on Road Signs and Signals opened for signature in Geneva on 1st March, 1973" (European Road Marking System) of the E.C.E. (Economic Commission for Europe).

The regulations of different countries should be consistent with these international standards. However, the regulations of the United States "Manual on Uniform Traffic Control Devices for Streets and Highways" differ to some extent from those of the European Road Marking System, although both are consistent with the Vienna Convention.

Road markings have a number of functions, which lie at different levels of decision making (see also Chapter 2).

The major functions are related to:

- selection of the route (warning signs, locations, etc., indicated by letters and words);
- selection of specific manoeuvres (stop signs, directional arrows, stop lines, zebra crossings, etc.);
- control of specific manoeuvres like rounding bends, negotiating intersections, etc. (side markings, delineators, etc.);
- selection and control of elementary manoeuvres at the vehicle handling level; this pertains primarily to the control of lateral position within the traffic lane (lane marker).

1.4 Illumination Aspects

As regards to the visibility aspects, we will concentrate on the markers actually on the road, as they are usually the most critical. Since it is only in exceptional cases they carry their own lighting [45 - 47] the visibility is in all cases dependent on the contrast between the marking and the adjacent portions of the road surface. Because the markings are placed directly on the road surface, the illumination (and hence the illuminance) on the marking and the adjacent portions of the road surface are to be considered for all purposes as identical. Thus, the contrast (the luminance contrast) is determined exclusively by the difference in the reflective properties of the marker and the road surface.

The reflectance of a body (i.e. the amount of light which is reflected by the body in the direction under consideration – usually the direction of the eye of the observer) can be described by the incident light (direction, quantity, spectral composition, etc.), the geometry of observer and the characteristics of the material of the body. This implies a large number of variables, and one should not be surprised to find that the assessment of the contrast between road markings and the adjacent portions of the road surface proves to be a rather complicated affair (for the measurement geometry see Chapter 5).

As regards the illumination, a distinction should be made between two ways of light incidence. The first is the illumination by day or by public lighting and the second is the illumination by headlights of car.

The first is more or less diffuse illumination (i.e. from several directions at the same point) such as prevails during the day and with public overhead lighting. Because at a specific point of the road surface, and thus also at the road marking attached at that point, the light comes from different (often very many) directions, the resulting luminance can be described rather precisely by the diffuse

reflection of the materials of the road surface and of the marking. As a first approximation one may suggest that as regards the visibility of road marking it is not necessary to make a difference between daylight and public lighting, nor to specify in detail the type of public lighting. In case of using low pressure Sodium-lamps problems of colour rendering must be taken into account.

The second system of illumination to be considered when dealing with road markings is the lighting by means of vehicle headlights. Here the direction of incident light coincides nearly (but not fully!) with the direction of observation. Furthermore, neither the direction of observation, nor the angular difference between these two directions may be considered as constant. In fact, all these may change quite considerably for different distances between the observer and the object and different classes of vehicles. Under heavy fog conditions diffuse illumination is in both cases more or less the type of illumination.

There are certainly overlapping areas between public illumination (moderate levels) and headlight use where the visibility of road markings is at least partly due to the headlight illumination.

Daylight levels of lighting can sometimes be so low as to require the use of headlights and pavement marking visibility can be affected by the type of public lighting, particularly where the level is high.

1.5 Reflection characteristics of road markings

When considering the reflectance of the markings, one must consider several aspects.

Firstly the properties of the material itself, secondly the properties of additives (e.g. glass beads), thirdly the shape of the material as it is used in road markings (e.g. corner-cube reflectors) and finally the state the marking is in. The last point is of major importance, particularly regarding dirt, wear and sometimes a layer of water on top of the surface [5, 12].

The different types of reflection are described in detail in the literature (e.g. [48, 49]).

In *diffuse reflection* the light is scattered in all directions alike, without any preference, so that the resulting luminance depends only on the illuminance and the reflection factor.

In *specular (mirror) reflection* Fresnel's law is followed, and the luminance of the object is zero seen from most directions. Only in the specular direction the luminance is not zero; then it equals the luminance of the light source, multiplied by the (specular) reflection factor.

Although these two ways of reflection of light are theoretical, it turns out that most practical surfaces in most applications can be considered as belonging to one or the other.

In *retroreflection* the luminous radiation is returned into the direction where it came from, this property being maintained over wide variations in the direction of the incident light. Retroreflectors of the prismatic (*corner-cube*) type consist essentially of mirrors that are placed in such a way (the way of a corner of a cube!) that all incident light is reflected three times, and it is re-emitted in the same direction from where it came – independent of the position of the reflecting element in relation to the incident beam. Prismatic retroreflectors come as rigid glass or plastic units, or as sheets.

Reflectors of the *glass-bead* type are in fact ordinary reflectors – usually of the diffuse reflecting type – where the glass beads serve as auto-collimators.

The effect of all retroreflectors is that most of the incident light is re-emitted into directions close to the direction where it came from.

It should be noted that a sphere of glass acts as a lens, focussing a parallel beam of light. When the lens is spherical and made of ordinary glass with a refractive index of some 1,5 to 1,7, the focal point will be behind the lens. A reasonable performance can be achieved only when a reflecting surface (e.g. of the specular kind) is placed at the focal point, i.e. at some distance *behind* the lens. This is the usual construction of retroreflecting materials of the sheeting type. In most road-marking materials, however, the glass spheres (or glass beads) are placed directly on or in a white, diffusely reflecting binder; in this case the performance is usually much lower than can be achieved with the sheet type materials (see [2, 9, 10, 28, 49 - 56]). The reason is that the collimating effect is not optimal when the reflector is not at the focal point, but ahead of it.

The effect can be avoided if glass with a refractive index of 2,0 is used, so that the focal point is exactly on the rear surface of the sphere (see [57]). Alternatively making the lens longer than would correspond with the sphere (the "elongated sphere"). With this last construction ordinary, cheap and wear-resistant glass may be used and still provide a good performance. Such elongated spheres cannot be used as pre-mixed or sprayed on beads but are usually made quite large, and are incorporated in the reflectors of the well-known "cat's eye" type.

As a final remark, it is customary to deal with the visibility of road markings by considering only the way drivers look at them. This, however, is obviously a restriction; when one e.g. considers the visibility of the road markings used for pedestrian crossings (zebra stripes), one must take into account the fact that a pedestrian looks at it from a completely different direction than an approaching driver.

1.6 Visibility of road markings

Under day conditions it is not difficult to make road markings in such a way that they are clearly visible. The major problem in marking roads, however, is to ensure adequate visibility at night also when the road is wet – particularly when the road is lit only by means of vehicle headlights. With a layer of water the light is mainly reflected at the outer surface of the water, so that the incident light does not enter the retroreflector. Thus, the differences in colour of wet objects mostly disappear, and, more seriously, in the case of road markings where the light strikes the surfaces at a glancing angle, the retroreflecting characteristics of the glass beads is impaired. This is the reason for the well-known fact that on wet roads the road markings are practically invisible, particularly at night under conditions of vehicle headlighting. However, the remedy is also obvious: re-adjust the reflecting elements of the road markings in such a way that the light does not strike them at a glancing angle or raise the reflecting element above the level of the water film on the road surface. In practice this means that the markers should stick out above the surface of the road. This can be effected by applying raised pavement markers, or corrugated markings. Both types are discussed later (see also [10, 11, 14]).

Raised pavement markers are not seen under heavy snow conditions and are vulnerable to snowplow operations, however, recent developments in U.S.A. seem to have reduced this problem.

1.7 Conclusions

The following remarks can be made regarding road markings in agreement with O.E.C.D. [5].

1. All marking devices are placed for the purpose of guiding, regulating or controlling traffic and as a source of information for the driver.

The following advantages are expected from the use of marking devices:

- considerable improvement of driving conditions (driver comfort), especially in conditions of poor visibility;
- improved traffic flow on roads and at junctions, increased traffic volumes and reduced journey times;
- positive benefits to traffic safety, especially in conditions of poor visibility.

Negative effects of properly applied marking devices are not to be expected.

2. The achievement of the required characteristics is made difficult by the following adverse factors (also refer to chapters 3 and 4):
 - poor visibility, in wet weather, especially of horizontal markings;
 - tendency of certain materials to decrease the luminance factor;
 - retention of dirt (especially by raised pavement markers and pavement-surface markings if they are not cleaned by traffic);
 - poor resistance to wear (painted pavement-surface markings), especially where studded tyres may be used;
 - poor adhesion characteristics of some materials on certain pavements.

2 Requirements for markings and raised pavement markers for driving at night and day

2.1 Introduction

In this chapter, the requirements for road markings (stripes and raised markers) are discussed in terms of the drivers visual perceptual needs. The discussion begins with a review of driver visibility distance needs, then describes calculations based on luminance, contrast, threshold values and other factors influencing road marking visibility. Experimental results are presented in support of the theoretical calculations. Although both nighttime and daytime conditions are discussed, the emphasis is on nighttime requirements, since these are usually considered most critical. In the conclusion, minimum requirements are suggested.

2.1.1 Visibility distance requirements

Visibility distance requirements relate to the need for preview information. Preview information is of two types, long-range and short-range. Long-range preview information relates to the course of the road ahead, such as curves or obstacles. Short-range preview relates to the lateral position and speed of the driver's car.

In setting requirements for a delineation system, both nighttime and daytime visibility must be considered, however, nighttime is of special interest, since there are few other features visible which might be used to provide preview information about the roadway.

Daytime situations, or nighttime situations with public lighting are not considered critical, because of the abundance of (unintentional) delineation information. Consequently, to be effective, requirements for materials are usually based on the most critical situation, that is at night on rural roads without public lighting and with the exclusive presentation of the specific delineation system.

2.1.2 Driver's visual geometry (Perspective scene)

Visual requirements for a delineation system relate to the drivers perception of the road ahead. This road scene perspective has longitudinal, lateral and vertical directions. What the driver sees depends on the optical characteristics of the road materials, what a driver needs to see is determined by minimum preview time or distance which is dependent on his speed. The position of the individual elements of the delineation system can be described in terms of a road scene geometry.

Optical characteristics of road marking material must meet certain requirements in order to provide sufficient visibility distance. The higher the reflective properties of a marking, the higher is its contrast with the road surface and its visibility distance increases. There are quantitative relations between optical characteristics and visibility distances.

In general it appears that the driver's short-range preview information in perceiving variations in the lateral position of the car is affected by the driver's perspective perception of the road ahead, and varies according to the $H / \sqrt{H^2 + Y^2}$ where H = height (m) of the driver's eyes above the delineation, and Y = mean lateral distance (m) between the eyes and the delineation. It can be shown that best short-range preview information is available when the delineation system is not above, but on the road surface (maximum H), or laterally close to the car (small Y). Long-range delineation information increases for larger vertical distances between the delineation system and the driver's eye height [58].

2.1.3 Preview time and distance requirements

It is possible, based on material optical properties, to calculate the visibility distance of road markings and conversely, once the visibility distance needs are established, it is possible to derive the minimum

optical characteristics required of the markings. Therefore the visibility distances or time intervals over which markings must be previewed in order to drive safely and comfortably must be discussed.

The literature does not provide abundant information about minimum preview times/distances. Weir and Mc Ruer [59] found a minimum of 5 s preview time necessary to allow for efficient, anticipatory steering behaviour. Allen et al. [60] established a smaller critical time of 3 - 4 s in a delineation study during adverse weather conditions. As a consequence, a 5 s minimum preview time seems to be a rather conservative but safe criterion. Taking into account the practical data quoted further on, a minimum preview time of about 3 s seems to be more applicable in practice.

For speed corrections during curve approaches Fig. 2.1 gives some additional values for required visibility distances for comfortable speed adjustments in accordance with:

$$d = t_r \cdot V_1 + \frac{V_1^2 - V_2^2}{2|a|}$$

with d = required visibility distance (m)

t_r = driver's reaction time (s)

V_1 = velocity during curve approach (m/s)

V_2 = velocity for safe curve negotiation (m/s)

$|a|$ = comfortable deceleration (m/s²)

Fig. 2.1 is based on a driver's reaction time of 1.5 s and a deceleration of 2 m/s².

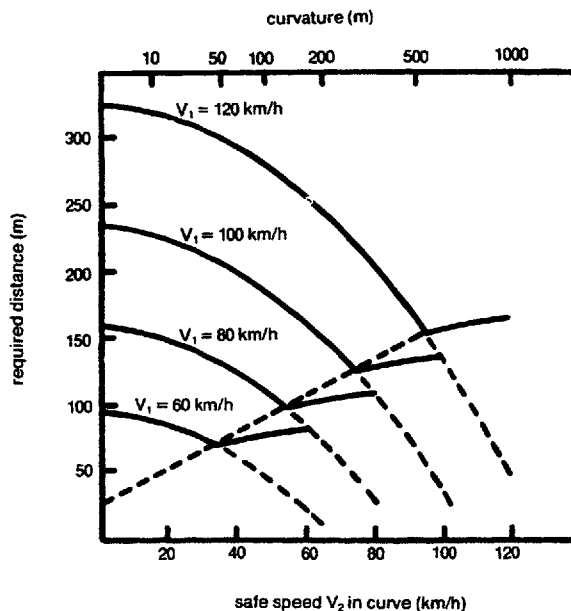


Fig. 2.1 Required visibility distances of a curve delineation system (from: Godthelp and Riemersma [58]).

For instance, if the approaching speed V_1 is 100 km/h and the safe speed V_2 is 60 km/h, then the required visibility distance for that curve is equal to 165 m. When no speed adjustments have to be made and drivers can continue with 100 km/h, as is usually the case on motorways, the visibility distance becomes equal to 140 m which corresponds to a preview time of 5 s. Although these data are not based on very extensive research they form a starting point in setting requirements for visibility distances.

More research is needed in order to extend the limited knowledge that exists about minimum preview times.

2.1.4 Terminology

The terminology that follows is a discussion of some of the terms used in this chapter and in part applies to both day and night visibility. Rigorous definitions are formed in other CIE documents such as the International Lighting Vocabulary [100] and CIE Publication 54 [49].

Luminance

Road surfaces, as well as road marking stripes are seen as plane surfaces. Brightness is the sensation observers perceive from the surface of an object. *Luminance* is the measurable photometric quantity related to visual brightness.

Luminance factor

The luminance factor is the *ratio* of the luminance of a surface to that of a perfect diffuser, when illuminated and viewed under the same geometric conditions.

Contrast

A road marking can only be differentiated from a road surface by viewing if its luminance differs from the luminance of the road surface. *Contrast* is defined as

$$C = \frac{L_M - L_S}{L_S}$$

L_M Luminance of roadmarking
 L_S Luminance of road surface

Threshold contrast

Threshold contrast is the term used to describe the contrast needed under specified conditions to make an object (stripe) just visible to the observer.

Retroreflective characteristics

The retroreflective characteristics of the materials are the coefficient of retroreflected luminance R_L for stripes and the coefficient of luminous intensity R for raised pavement markers, which can be considered as point light sources [33].

Coefficient of retroreflected luminance (R_L)

This is a surface property. It is the quotient of the luminance L of the surface of the material in the direction of observation by the illuminance $E_{\perp}$ at the surface on a plane to the incident light (see 5.3). The unit is $\text{cd} \cdot \text{m}^{-2} \cdot \text{lx}^{-1}$. When the illumination is known it can be used to calculate the luminance as seen by the observer. For this quantity $\text{mcd} \cdot \text{m}^{-2} \cdot \text{lx}^{-1}$ is often used to avoid fractional values.

Coefficient of (retroreflected) luminous intensity (R)

This is an object property. It is the quotient of the luminous intensity of a retroreflective object (treated as an apparent point source) and the illuminance on the object, measured normal to the source under specified geometric conditions. The unit is $\text{cd} \cdot \text{lx}^{-1}$. Definition see 5.8.2.1.

2.2 Nighttime visibility of road markings

2.2.1 General

This section describes the calculations of visibility distances at night from the material characteristics, R_L and R , for Road Stripes and Raised Road Markers. Results of these calculations for various conditions are shown in figures 2.2 and 2.3.

Data for the calibration of these models was gathered by the Institute for Perception TNO for the Dutch Working Group E9 and are based on

- measurements of the optical characteristics of various types of stripes and raised pavement markers, and
- experiments with subjects in order to determine visibility distances.

Both types of measurements were combined in order to calibrate a general model predicting visibility distances as a function of optical properties of markings at specified meteorological visibilities and headlight intensities on dry and wet roads [33].

The following section presents the model equations in detail.

2.2.2 Visibility distances of stripes

The visibility of continuous stripes is defined by the luminance contrast between stripe and road surface, in relation to the threshold contrast of the human observer. This threshold value can be related to the data of Blackwell [61], in which it is derived which contrast is needed to perceive small circular targets in the laboratory, as a function of the surrounding luminance L_S and target diameter d_t . The threshold contrast C_{th} can be approximated by:

$$C_{th} = \frac{2}{\sqrt{L_S d_t^3}}, \quad \text{for } 0,02 \leq C_{th} \leq 1 \quad (1)$$

$$10 \leq d_t \leq 50 \text{ min of arc}$$

$$0,001 \leq L_S \leq 1 \text{ cd} \cdot \text{m}^{-2}$$

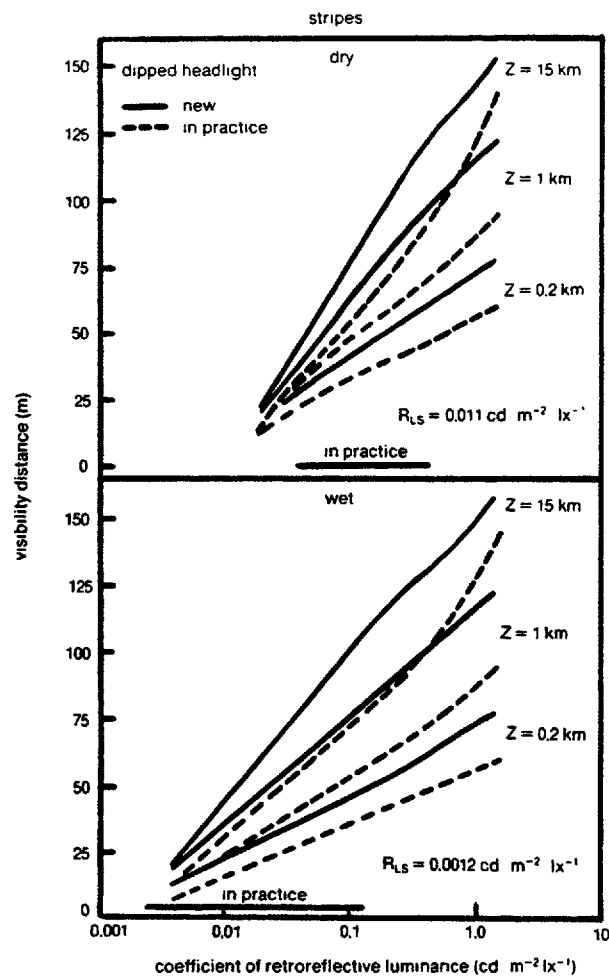


Fig. 2.2 Predicted relations between the coefficient of retroreflective luminance of stripes and visibility distances on wet and dry roads for three values of meteorological visibility ($Z = 15$, 1 and 0.2 km for clear weather, moderate fog, and heavy fog, respectively) and for new and in practice values of dipped headlamp intensities. Coefficients of retroreflective luminance which can be realised in practice are also indicated on the horizontal axes. R_{LS} refers to the coefficient of retroreflective luminance of a specific road surface.

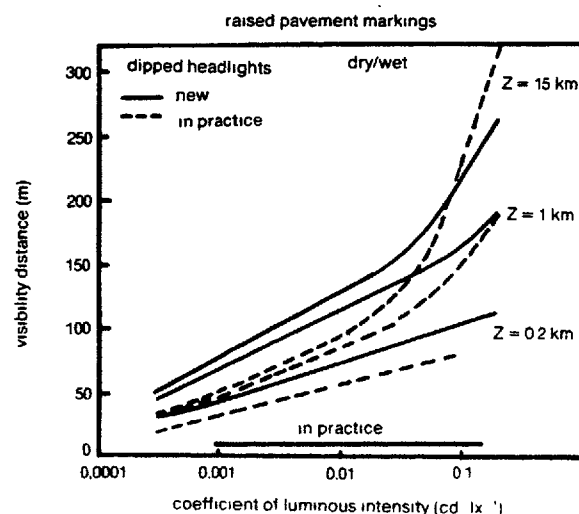


Fig. 2.3 As figure 2.2 but now for the relations between the coefficient of luminance intensity of raised pavement markings and visibility distance

For object perception in practice the threshold contrast C'_{th} is assumed to be a factor k' (> 1) times the laboratory threshold C_{th} . Furthermore, it is hypothesized that at any distance the local area of the stripe (with a angular width w and height h) can be set equal to the area of a circular target with diameter d_{eq} :

$$\frac{\pi}{4} d_{eq}^2 = w \cdot h \quad (\text{min of arc}^2) \quad (2)$$

The angular width w of the stripe at a distance d (m) is equal to:

$$w = 120 \cdot \arctan \left[\frac{w_0}{2d} \right] \quad (\text{min of arc}) \quad (3)$$

with w_0 as the actual width of the stripe (m). w_0 has been fixed in the calculations to a value of 0,15 m. The height h (min of arc) is assumed to be unknown as yet, and is coupled with the factor k' into a final correction factor k . Substitution of (2) and (3) in (1) gives:

$$C_{th} = h^{-3/4} \cdot 2 \cdot L_S^{-1/2} \left[\frac{480}{\pi} \arctan \left(\frac{w_0}{2d} \right) \right]^{-3/4} \quad (4)$$

Because $C'_{th} = k' \cdot C_{th}$, then (5)

$$C'_{th} = k \cdot 2 \cdot L_S^{-1/2} \left[\frac{480}{\pi} \arctan \left(\frac{w_0}{2d} \right) \right]^{-3/4} \quad (6)$$

where: $L_S = \frac{R_{LS} \cdot I}{d^2} \cdot e^{-6d/Z} + \frac{15}{Z}$ (6a)

with: R_{LS} = coefficient of retroreflected luminance of the road surface ($\text{cd} \cdot \text{m}^{-2} \cdot \text{lx}^{-1}$)

I = headlight intensity (cd)

d = distance (m)

Z = meteorological visibility, defined as the distance (m) with a contrast transmission of 5%.

Experimentally it is found over a group of subjects that

$$k = k' \cdot h^{-3/4} = 3,6 \quad (7)$$

ranging from 1,8 to 7,0.

At this time, the threshold contrast can be compared with the available contrast C between marking and road surface, in accordance with

$$C = \frac{(R_{LM} - R_{LS}) \cdot I \cdot d^{-2} \cdot e^{-6d/Z}}{R_{LS} \cdot I \cdot d^{-2} \cdot e^{-6d/Z} + 15/Z} \quad (8)$$

with R_{LM} = coefficient of retroreflected luminance of the marker ($\text{cd} \cdot \text{m}^{-2} \cdot \text{lx}^{-1}$)

In equation (8) it is assumed that the marker is only illuminated by the headlights (the nominal intensity as a function of d has been presented by Blaauw and Padmos [33]), with the atmospheric scattering and extinction taken into account. Valetton and Vos [62] estimated that the veiling luminance of the atmosphere can be approximated by the term $15/Z$ ($\text{cd} \cdot \text{m}^{-2}$) when dipped headlamps are used; see also Godthelp [63] for a field validation of these data. The equations can be adapted for the additional veiling luminance from public lighting or glare from opposing traffic.

The visibility distance of a marker can now be determined by plotting C'_{th} and C according to the equations (6) and (8) at different distances d , and determining the intersection of $C'_{th}(d)$ and $C(d)$.

2.2.3 Visibility distances of raised pavement markers

The visibility of raised pavement markers, which may be considered as point light sources, is defined by the illuminance produced by the marker at the eye, in relation to the threshold illuminance of the human observer. This threshold illuminance E_{th} is dependent on the surround luminance L_S . This relation can be derived for individual point light sources from laboratory data of Blackwell, see e.g. Padmos and Vos [64]. It appears that E_{th} is equal to $3 \cdot 10^{-8} \text{ lx}$ for foveal vision for $L_S \leq 0,3 \text{ cd} \cdot \text{m}^{-2}$.

For the situation of raised pavement markers it is necessary to consider many point light sources at the same time, because the markers are separated only by very small visual angles. At increasing distance the number of raised pavement markers is 'condensed' and the markers support each other. Therefore, the threshold illuminance E_{th} for one marker has to be corrected for n markers which are perceived within an integration angle α of the human eye:

$$E'_{th} = \frac{E_{th}}{n} \quad (9)$$

with

$$n = \frac{2H \cdot (H^2 + d^2) \cdot \operatorname{tg}\left(\frac{\alpha}{120}\right)}{d_r \cdot \left[H^2 - d^2 \operatorname{tg}^2\left(\frac{\alpha}{120}\right) \right]} \quad (10)$$

and H = height of observers eye (m)

d = distance (m)

d_r = distance between raised pavement markers (m)

α = integration angle of the eye (min of arc)

For observations in practice it is assumed that the threshold illuminance E''_{th} is a factor k (≥ 1) greater than the laboratory-based threshold E'_{th} :

$$E''_{th} = k E'_{th} \quad (11)$$

Experimentally it is found over a group of subjects that

$$k = 34,7 \quad (12)$$

ranging from 25,0 to 43,1. Thereby it is assumed that $\alpha = 15$ min of arc.

At this time, the threshold illuminance can be compared with the actual illuminance E_{eye} , according to:

$$E_{eye} = \frac{R_M}{d^4} \cdot I \cdot e^{-6d/Z} \quad (13)$$

with R_M = coefficient of luminous intensity of the markers ($\text{cd} \cdot \text{lx}^{-1}$)

d = distance (m)

I = headlight intensity (cd)

Z = meteorological visibility.

The visibility distance of a raised pavement marker can now be determined by plotting $E''_{th}(d)$ according to Eqs. (9), (10) and (11) and $E_{eye}(d)$ according to Eq. (13), for various distances d , and determining the intersection of both curves.

Moukhwas and Bry [65] found for the raised pavement markers that the visibility distances show a more gradual increase than suggested by Fig. 2.3 for coefficients of luminous intensity exceeding $0,1 \text{ cd} \cdot \text{lx}^{-1}$.

2.2.4 Measurements in practice

Data are available on the optical characteristics and visibility distances of various marking systems in practice and especially during the critical nighttime situation with wet roads. The Dutch Working Group E9 supervised the application of several stripes (traffic paint, thermoplastic material, stripes with a vertical profile) and raised pavement markers on a motorway section, and studied the optical characteristics and visibility distances as a function of wear, rain, fog and dew [33, 34].

Fig. 2.4 shows the visibility distances (determined from their measured optical characteristics by means of the relations presented in Figs. 2.2 and 2.3) for materials immediately after application, during dry and wet conditions for these meteorological situations. Although the visibility distances of conventional materials such as paint and thermoplastics appeared to deteriorate to a large extent for wet conditions, the more recently available materials – profiled stripes and raised pavement markers – are not too sensitive to rain. The horizontal lines in each figure refer to the required visibility distances based on the afore-mentioned required preview time of 5 s. For roads with V_{85} velocity (85 percentile of the velocity distribution) of 80 and 100 km/h this translates to visibility distances of 110 m and 140 m respectively. During heavy fog conditions ($Z = 0,2 \text{ km}$) the effective V_{85} velocity on these types of roads decreases and the corresponding required visibility distances are set to 100 m and 110 m. Table 2.1 presents data for the visibility distances of these materials after about two years traffic. It can be concluded again that all newer materials offer better alternatives for the nighttime visibility during wet conditions.