



COMMISSION INTERNATIONALE DE L'ÉCLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

LIGHT SIGNALS FOR ROAD TRAFFIC CONTROL

PUBLICATION CIE N° 48 (TC-1.6) 1980
BUREAU CENTRAL DE LA CIE
52, BOULEVARD MALESHERBES 75008 PARIS - FRANCE

This report has been prepared by CIE Technical Committee 1.6 Visual Signalling. It has been approved by the majority of the Technical Committee and is recommended for study and application. This report is not an Officially Agreed CIE Recommendation approved by the National Committees of the Member Countries of the CIE. It should be noted that any recommendations in this report are advisory and not mandatory. The latest CIE Proceedings or CIE Bulletin should be consulted regarding the current status of this report and possible subsequent amendments.

Ce rapport a été préparé par le Comité Technique 1.6. Signalisation visuelle de la CIE. Il a été approuvé par la majorité du Comité Technique et il est recommandé pour étude et application. Ce rapport n'est pas une Recommandation officielle de la CIE, approuvée par les Comités Nationaux des Pays Membres de la CIE. Il doit être noté que toute recommandation y figurant est donnée à titre de conseil et non d'obligation. En ce qui concerne la situation présente de ce Rapport et d'éventuelles modifications, il faut consulter le plus récent Compte Rendu de Session ou Bulletin de la CIE.

Dieser Bericht wurde vom Technischen Komitee 1.6 Verkehrssignale der CIE ausgearbeitet. Er wurde durch die Mehrheit des Technischen Komitees gebilligt und wird zum Studium und zur Anwendung empfohlen. Dieser Bericht ist keine offiziell anerkannte CIE-Empfehlung, der die Nationalen Komitees der Mitgliedsländer der CIE zugestimmt haben. Es sei darauf hingewiesen, dass jede Empfehlung in diesem Bericht als Anleitung dient und nicht verbindlich ist. Was den gegenwärtigen Status dieses Berichtes und mögliche Nachfolge-Ausgaben angeht, ziehe man die neuesten CIE-Tagungsberichte oder das CIE-Bulletin zu Rate.

ISBN 92-9034-048-7

FOREWORD

During its meeting in January 1973, CIE Technical Committee 1.6, Visual Signalling, accepted a request to add a study of the fundamentals of road traffic light signals to its work programme. A subcommittee was appointed to draft a Technical Report which would serve as a background paper for international recommendations on road traffic light signals. The subcommittee submitted its draft of the Technical Report to Technical Committee 1.6, which reviewed and edited the document.

Members of Technical Committee 1.6 during the preparation of this report :

B.L. COLE	Australia
R. GEETS	Belgium
H. NIKOLOV	Bulgaria (1971-1975)
J.D. MORELAND	Canada
J. JUZEK	Czechoslovakia
B. BUCHMANN	Denmark
T. TIMONEN	Finland
P. BLAISE	France, Chairman (1977-)
P. JAINSKI	Germany, Federal Republic (1971-1975)
H. TERSTIEGE	Germany, Federal Republic (1975-)
L.G. REYNOLDS	Great Britain
I. HAUSER	Hungary
E. QUARANTA	Italy (1971-1975)
M. ARTOM	Italy (1975-)
H. MASAKI	Japan
P.L. WALRAVEN	The Netherlands
T.O. PEDERSEN	Norway (1971-1975)
W. FELHORSKI	Poland
L. STOENESCU	Romania
A. DEL PALACIO	Spain
F. STRUTT	South Africa (1975-)
F. ZACHERINI	Sweden (1971-1975)
K. RUMAR	Sweden (1978-)
C.A. DOUGLAS	USA, Chairman (1971-1977)
D.A. NAUS	USA, Secretary (1976-1977)
W.W. WHITE	USA, Secretary (1971-1976)
V.G. BARYSHNIKOV	USSR (1975-)

Members of Sub-Committee on Road Traffic Light Signals

A. FISHER	Australia
R. PAGÈS	France
G. SCHREIBER	Germany, Federal Republic
J.G. HOLMES	Great Britain (1973-1975)
B.M. COBBE	Great Britain (1975-1978)
D.A. SCHREUDER	The Netherlands, Chairman
R.E. CONNER	USA

Consultants to TC-1.6 on Road Traffic Light Signals

G. VERRIEST	Belgium
A.M. SERRES	France
W. ADRIAN	Germany, Federal Republic
J.G. HOLMES	Great Britain (1976-1978)
A.V. HORDEN	Great Britain
C.W. MORTIMER	Great Britain
H.F. STEPHENSON	Great Britain
K. NARISADA	Japan
J.B. DE BOER	The Netherlands
A.L. BURG	USA
C.A. DOUGLAS	USA (1977-)

SUMMARY

The purpose of this report from the CIE Technical Committee 1.6 is to provide information that will be relevant to an understanding of future recommendations on light signals for road traffic control. The report is restricted to matters that are of direct concern to the road user, and it is not concerned with the regulatory status of traffic light signals.

There is firstly a review in general terms of subjects related to the visual effectiveness of the light signals : attention, perception, vision, factors adverse to visibility, and traffic engineering. In spite of the complexity of the traffic situation and the driving task, agreement can be reached on the colorimetric and photometric requirements of the signal lights. Many investigations have been made into the factors likely to influence the detection of signals, and their conclusions enable suitable specifications to be written for signal lights with regard to colour, luminous intensity and luminous intensity distribution. Although a signal may be capable of generating a visual response in a driver, he may not be aware of it owing to various distractions. Clearly, traffic engineering must be considered in association with the specifications for the lights in order to minimize the decision-making demands on a driver approaching signal lights, and, furthermore, care must be taken in positioning the lights in relation to the driver's field of view. The report also comments upon the problems of sun phantom, and the shape and sizes of symbols used with lights. The last section puts some suggestions for specifications for light signals for road traffic control.

RÉSUMÉ

SIGNAUX LUMINEUX DE CONTRÔLE DE LA CIRCULATION ROUTIÈRE

L'objet du présent rapport du Comité Technique C.I.E. 1.6 est de fournir les informations nécessaires à la compréhension des futures recommandations sur les signaux lumineux de contrôle de la circulation routière. Le rapport se limite aux problèmes intéressant directement l'usager de la route et ne concerne pas la réglementation des signaux lumineux de circulation.

Il présente tout d'abord des généralités sur des facteurs intervenant dans la visibilité des signaux lumineux : attention, perception, vision, gênes diverses à la visibilité et technique de la circulation. Malgré la complexité de la circulation et de la conduite il est possible de se mettre d'accord sur les caractéristiques colorimétriques et photométriques des signaux lumineux. De nombreuses recherches ont été consacrées aux facteurs susceptibles d'influer sur la détection des signaux et leurs conclusions permettent de rédiger des spécifications convenables pour les signaux lumineux en ce qui concerne leur couleur, leur intensité lumineuse et leur diagramme de rayonnement. Bien qu'un signal soit suffisant pour déclencher la réponse visuelle d'un conducteur, il peut passer inaperçu du fait de distractions de tous ordres. Il est certain que la technique de la circulation doit être prise en compte conjointement aux spécifications des feux de façon à minimiser les exigences de la prise de décision pour un conducteur arrivant à proximité des signaux lumineux et en outre, il faut prendre soin de placer les feux en fonction du champ visuel du conducteur. Le rapport aborde aussi les problèmes de l'effet fantôme dû au soleil et de la forme et des dimensions des feux à symboles. La dernière partie avance quelques suggestions pour les spécifications des signaux lumineux de contrôle de la circulation routière.

ZUSAMMENFASSUNG

LICHTSIGNALLE FÜR DEN STRASSENVERKEHR

Der Zweck dieses Berichts vom Technischen Komitee CIE-1.6 ist es, schon jetzt die notwendigen Informationen zur Verfügung zu stellen, die für das Verständnis zukünftiger Empfehlungen für Lichtsignale zur Regelung des Straßenverkehrs (Straßenverkehrssignale) notwendig sind. Der Bericht behandelt nur das, was den Straßenbenutzer direkt betrifft. Er befaßt sich nicht mit der verkehrsregelnden Bedeutung der Straßenverkehrssignale.

Es wird zunächst ein allgemeiner Überblick über Themen gegeben, die mit der visuellen Wirkung von Lichtsignalen verbunden sind : Aufmerksamkeit, Wahrnehmen, Sehen, für das Sehen ungünstige Faktoren und Verkehrstechnik. Trotz komplexer Verkehrssituation und Fahraufgaben kann über die farbmetrischen und photometrischen Anforderungen an Signallichter Einigung erzielt werden. Viele Untersuchungen sind dazu unter Bedingungen durchgeführt worden, die das Wahrnehmen und Erkennen von Lichtsignalen beeinflussen. Die Ergebnisse dieser Untersuchungen ermöglichen es, geeignete Vorschriften für die Farbe, die Lichtstärke und die Lichtstärkeverteilung von Signallichtern aufzustellen. Obwohl ein Signal eine visuelle Reaktion beim Fahrer auslösen kann, könnte er es wegen verschiedener Ablenkungen nicht gewahr werden. Dies bedeutet, daß Verkehrstechnik in Zusammenhang mit den Vorschriften für die Signallichter gesehen werden muß, um die entscheidungsbildenden Anforderungen an den sich einem Lichtsignal nähernden Fahrer zu minimieren. Darüber hinaus müssen die Lichtsignale im Sehfeld des Fahrers richtig aufgestellt sein. Der Bericht geht auch auf das Problem des Phantomlichts sowie auf Form und Größe der für die Signallichter benutzten Symbole ein. Der letzte Abschnitt enthält einige Vorschläge für Vorschriften über Straßenverkehrssignale.

TABLE OF CONTENTS

1. SCOPE	1
2. SUBJECTS RELATED TO THE VISUAL EFFECTIVENESS OF LIGHT SIGNALS FOR ROAD TRAFFIC CONTROL	2
2.1. Introduction	2
2.2. Attention	2
2.2.1. Types of Attention	2
2.2.2. Internal Factors Affecting Attention	3
2.2.3. External Factors Affecting Attention	3
2.3. Perception	4
2.3.1. Detectability and Conspicuity	4
2.3.2. Recognition	4
2.4. Vision	5
2.4.1. Defective Colour Vision	5
2.4.2. Visual Acuity	5
2.4.3. Visual Performance	6
2.4.4. Flashing Lights	6
2.5. Factors Adverse to Visibility	7
2.6. Traffic Engineering	7
2.6.1. Visual Range of Signals	7
2.6.2. Intersection Design and Positioning of Signals	8
3. COLORIMETRIC AND PHOTOMETRIC REQUIREMENTS	10
3.1. Introduction	10
3.2. Factors Affecting Signal Requirements	10
3.3. Colour Recognition	11
3.4. Luminous Intensity for Unrestricted Signal Lights	11
3.4.1. Background Luminance	11
3.4.2. Size of Signal Light	13
3.4.3. Luminous Intensity of Signal Lights for Daytime Conditions in Relation to Background Luminance and Distance	13
3.4.4. Luminous Intensity Requirements of Signal Lights for Night-time Conditions	15
3.4.5. Modifying Factors	16
3.4.5.1. Position of the Signal in the Field of View	16
3.4.5.2. Background Screens	17
3.4.5.3. Effects of Colour on Intensity Requirements	18
3.4.5.4. Sun-Phantom Effects	18
3.4.5.5. Non-Neutral Optical Media	20
3.5. Desired Signal Range	20
3.6. Derivation of Luminous Intensity Distribution of Signal Lights	22
3.7. Restricted Signal Lights (Lights with Symbols)	25
3.7.1. Shape of Figures and Symbols in Restricted Signal Lights	25
3.7.2. Direction Control Signal Lights	26
3.7.2.1. Symbol Shape and Colour	26
3.7.2.2. Arrow Shape	26
3.7.2.3. Summary of Requirements of Directional Signal Lights	27
3.8. Noisy Backgrounds	27
4. SUGGESTIONS FOR SPECIFICATIONS FOR LIGHT SIGNALS FOR ROAD TRAFFIC CONTROL	29
4.1. Size of Signal Lights	29
4.2. Colour Boundaries	29
4.3. Luminous Intensity	31
4.4. Luminous Intensity Distribution	31
4.5. Uniformity of Luminance over the Face of the Signal Light	32
4.6. Specifying the Phantom Effect	32
4.7. Shape of Figures and Symbols in Restricted Signal Lights	33
REFERENCES	34

1. SCOPE

This report is concerned only with matters that directly influence the road user in his perception of road traffic signals. It does not cover other important matters concerning traffic signals : the location of signal lights and the coupling of them within and between road intersections; the regulatory status, which includes the number and sequence of colours in the system, and the legal obligations of local authorities and the road user; and electrical and mechanical engineering, which includes standardization and interchangeability.

The visibility of light signals depends on many factors, the most important of which for this report are the colour, the luminous intensity and the luminous intensity distribution of the lights. Since the correct recognition of a traffic signal light may be seriously affected by sun phantom, this problem is discussed also. Nowadays recognition of « cut-out » figures, or symbols, used with lights has become important, so the report examines some details of their shape and size. Some of the design considerations for traffic engineering are also included.

The report contains a discussion of flashing signal lights, but it does not deal with flashing yellow lights that are used for warning only.

The terminology in the report is usually in accordance with the « International Lighting Vocabulary » (CIE, 1970).

2. SUBJECTS RELATED TO THE VISUAL EFFECTIVENESS OF LIGHT SIGNALS FOR ROAD TRAFFIC CONTROL

2.1. INTRODUCTION

The function of light signals for road traffic control is to improve the quality of service of the road network. This quality can be expressed in terms of *road safety*, *travel speed* and *road capacity*, and *driver comfort and convenience*. The functional approach to traffic facilities is treated in detail by Schreuder (1971). When the need for traffic control signals and their characteristics are deliberated, the conclusions reached may differ according as to which one of the above objectives has been under consideration. Thus, there may be three distinct sets of reasons for the introduction of traffic control signals. For all three sets, the visibility of the signal is essential, and it can be argued that it is chiefly the distance from which the signal should be observed that distinguishes the sets. The observation distance in its turn follows from the considerations of traffic engineering.

There now exists a substantial amount of data on which these ideas are based. As an introduction, Chapter 2 discusses some of the more general related subjects, such as the concepts of Attention (2.2.) and Perception (2.3.), Vision (2.4.), Factors Adverse to Visibility (2.5.) and Traffic Engineering (2.6.).

2.2. ATTENTION

2.2.1. Types of attention

Attention has been described by Krech and Crutchfield (1968, pages 102-106) as

« the selective focusing upon certain points or aspects of the situation. That part of the perceptual field which is the center of focus attention is clearer, more salient, more differentiated than other parts. It stands out as *figure* against the rest of the field, which is *ground*. The duration of a given focus of attention is usually brief. There is a constant shifting of attention from one part to another. Attention shifts for several reasons. For one thing, there is in attention, as in all psychological processes, a form of *satiation* which tends to inhibit the continuance of attention in a given direction. The attention at any one moment may be distributed in various ways over the whole field. It can be concentrated in one point. It may be diffusely spread so that no particular part is primarily in focus. It may be *divided*, the person trying to attend to two or more things simultaneously. There are strict limits to the extent of such divided attention. The more the division, the more the loss in quality of attention devoted to each part. Attention is commonly spoken of as either *voluntary* or *involuntary*. The former pertains to cases in which the individual seems to have freedom in determining his own focus to attention. Involuntary attention pertains to cases in which the person seems less a free agent choosing the direction of his attention and more the pawn of forces that *require* him to attend this way or that ».

The distribution of attention, particularly as regards signal lights, has been dealt with in much detail by Pagès (1960), which may be translated as :

« It is therefore necessary, in order that the signal be functional, that the stimulus should provoke a sensation strong enough to make perception possible. It should, therefore, be above both the physiological and the psychological thresholds. The latter is related to the state of attention of the observer.

One may discern three types of attention :

- concentrated attention,
- diffuse attention,
- dispersed attention.

Concentrated attention is the most simple to define. The observer has no other activity than to perceive the signal. This is the case of the lookout who looks for a lighthouse signal, the position of which is known a priori.

Usually in road traffic this is not the case. Although a good driver concentrates his attention exclusively to the driving of his car, he has to perform several tasks simultaneously, including the perception of signals. This is designated as *diffuse* attention.

Finally, the attention of the driver may be divided between driving his car, which he can do nearly automatically, particularly on a monotonous or a well-known road, and other preoccupations, such as business, a passenger, etc. Here one has to do with stimuli that present themselves in an irregular fashion. This is *dispersed* attention.

For obvious reasons, the most simple case, i.e., the concentrated attention, has been studied most. Much of the technical literature is related to this subject which, considering our earlier remarks, is of practically no use ».

Attention is important in the observation of all objects, including traffic signals. The degree to which the attention is focused on the signal has great influence on the probability that it will be observed. Observation is more than the mere projection of light on the retina of the eye; it necessitates the conscious apprehension of the stimulus light, more particularly in those circumstances in which a conscious decision has to be taken after the perception of a signal light, and the « message » given by the signal is coded. It is to be expected that many *external* factors may influence the outcome of the decision process initiated by the presence of the (light) signal, and hence also the resulting manoeuvre. It should be emphasized that nearly all of these external factors are negative; that is, the probability of a correct manoeuvre will be less than in the ideal case. Ultimately, the factors have to be translated back into an increase in the luminous intensity (or in the luminance) of the signal lights.

2.2.2. Internal factors affecting attention

Some of the factors that influence attention might conveniently be called *internal*. They have to do with psychological influences (« set », stress, motivation) and with physiological influences (use of alcohol and drugs, fatigue). It is not easily quantifiable, but it is generally accepted that a fairly large margin of luminous intensity is necessary over the minimum value for perception. As these factors are not constant, it is difficult to give any fixed value for this margin.

An important factor is the state of mind of the observer. In psychological literature this is usually indicated as « set » : an attitude or predisposition that renders a person liable to particular types of thought, perception or action.

In road traffic, « set » mainly has to do with the expectation that a traffic signal is at a particular location. Every car driver may expect, and may be presumed to expect, traffic signals within town centres and on main urban roads. On motorways, however, traffic signals are rare and can easily be overlooked or mistaken by the driver as belonging to an unimportant class of other lights. Therefore, it is of great importance when drafting photometric requirements for traffic signals to consider the road and the traffic situation where the signals will be located. On motorways, it has been found that traffic signals are of real use only if they are preceded by warning signals or signs, speed restrictions, and the like.

2.2.3. External factors affecting attention

Some factors relate to the *external* environment. The most important environmental factor is visual adaptation. A signal light should in most situations have a higher luminance than the luminance of the surrounding area. The desired ratio is not constant, and, within limits, is dependent upon the size of the signal light. However, signals should be much brighter in full daylight than in the dark in order to be readily discernible. Details are given in Section 3.4.

A second important environmental factor is *glare*. When the light is very much brighter than the surroundings, it causes direct glare. On these grounds, it is usually recommended that signal lights for road traffic that must function both by day and by night have at least two levels of intensity. These levels, however, need not be separated by a factor of a million, as are the average luminances by day and night, but the minimum intensity desired for daytime use is often considerably higher than the maximum value desired for night-time use. See Section 3.4.4.

Finally, it is important to note that the *general composition of the field of view* may have considerable influence on whether signals are observed or not. In particular, if the signal light is eccentric to the general line of sight it may be easily overlooked. This effect may be described in terms of the diffusion of the attention and, based on this, the requirements are set up for the angular distributions of the intensity of the signal lights (Fisher, 1971b). See also Section 3.6.

2.3. PERCEPTION

The considerations given above can be indicated in terms of *perception*. It is customary to distinguish between perception proper, or *detection* of the signal, on the one hand and *conspicuity* of the signal on the other hand.

2.3.1. Detectability and conspicuity

The *detectability* of a signal is usually understood as the property of the signal that enables its presence to be detected by an average observer under favourable circumstances with regard to attention, atmospheric conditions, etc., when the observer has no other task to perform.

In laboratory terms, detection is usually concerned with threshold values. The meaning of *threshold value* has been treated elsewhere in full detail (see e.g., CIE, 1972, and Fisher & Cole, 1974). The *conspicuity* of a signal, however, has little or nothing to do with threshold values. This property indicates how far the signal stands out with respect to other similar but irrelevant « signals ». Therefore, it has as much to do with the properties of the surroundings as with the properties of the signal itself. Furthermore, it is customary to include within the concept of conspicuity factors related to the distribution of attention, in such a way that the conspicuity of a signal is understood as meaning a property of the signal that facilitates detection by a « normal » observer in the presence of all disturbing signals that may be typical of the particular traffic situation. Also included is the consideration that the observer cannot concentrate exclusively on the detection of the signal, but has other functions to perform. Obviously, in most cases, the intensity or luminance requirements for adequate conspicuity are far higher than for adequate detectability, often a hundred or a thousand times higher. Nevertheless, no general rules can be given. A number of considerations are indicated by Fisher & Cole (1974), as will be clear from the following extracts.

EXPERIMENTAL METHODS

« General observations of road user behaviour can be made in real situations. The overall success of an in-service signal installation can be gauged by increased flow and safety. However, the complexity of this situation and lack of control over factors likely to influence signal light requirements, together with the ethics of on-site experimentation, preclude the use of such observations to determine optimum requirements.

Most investigators, the authors included, have resorted to laboratory simulations of the signal situation or have made static outdoor observations. Driving is a complex psycho-motor task incorporating a three stage process of perception, decision and implementation. Simulations have been made of the first stage, i.e., perception of a signal light, and the factors thought to influence the signal requirements have been investigated systematically and independently...

MEASURES OF PERCEPTION

The probability of detecting a light stimulus depends on its intensity. At low intensity it will be seen only occasionally, but as the intensity is increased the probability of seeing rises sharply until it will be rarely missed. This phenomenon yields the general and basic S shaped curve relating probability of detection to stimulus intensity. A road traffic signal should have an intensity which gives rise to a very high probability of detection. However, it is difficult to interpret the curve near the 100 per cent level. Many experimental observations are required to give a reliable result and resolution is inherently poor, the abscissa being in log units ».

Fisher & Cole (1974) also remark that, with increasing stimulus intensity, the reaction time decreases. It can be argued that not only a high probability of detection, but also a short reaction time, is required. As a matter of fact, both probability of detection and reaction time have been used to establish photometric requirements for traffic signals.

It should be noted here that, in addition to the deviations from the characteristics of the « normal » driver caused by age and defective colour vision, one must also consider the existence of drivers who are inattentive, tired, or who may be affected by drugs or alcohol. As has been indicated previously, these considerations may require an extra « safety margin » in the design of traffic lights.

2.3.2. Recognition

Another aspect of perception is *recognition*. Often it is not enough to detect the presence of an object, or light, be it isolated or in real surroundings. With traffic signals, it is necessary not only to recognize a light as

a signal light, but also to recognize the signal that has been transmitted by the light. This latter process is referred to as « decoding » the message of the (light) signal. It is clear that in road traffic it is *important to* recognize objects or lights and to be able to judge to which class they belong. Functionally speaking, this means the recognition of the action required in response to the presence of the object or light (see Schreuder, 1971, 1974). With traffic signals, this is even more important because of the rather abstract code which is generally in use for the message of the signal. For example, « red » has been given the meaning of : « stop at the stop line ».

It is important that a signal should *not* be seen in such a way that an inattentive driver might receive the wrong message. For example, if a signal light is not fitted with adequate screening (the visor) or is not provided with a suitable optically controlled beam to prevent its being seen from a road (or traffic lane) to which it does not apply, a colour change in the signal may be incorrectly interpreted by an inattentive driver in that road as having application to him. Pedestrian signal lights will need to be screened if there exists any risk of confusion if drivers see them. Equally important is the need to avoid wrong messages due to phantom effects (see Section 3.4.5.4.).

The aspects of perception discussed in this section may be summarized as follows : *detection* may be described in terms of threshold visibility and can be determined in laboratory experiments. *Recognition* can be treated to a certain extent in the same way, but *conspicuity* can only be investigated in real or simulated traffic situations, and can be described only in terms of « supra-threshold visibility ».

2.4. VISION

2.4.1. Defective colour vision

The characteristics of colour vision are subject to variation, but people with gross variations from the normal are said to have defective colour vision. (The expression « colour blindness » is strongly deprecated). Unless a colour defect is very severe, a person may be unaware of not possessing normal colour vision; and, at present, examination of the general population by means of proper colour tests is not internationally widespread. Defective colour vision is nearly always congenital, but it may be acquired exceptionally as a result of disease, the use of drugs, or old age. Studies have indicated that the proportion of the population subject to it may reach 8.0 per cent of males and 0.6 per cent of females : the common forms of defect are generally of a sex-linked genetic nature. Loss of all colour discrimination is fortunately rare.

Almost all of the people with defective colour vision may be termed « red-green confusers », for which one symptom is partial or total loss of discrimination between red, yellow and green, that is confusion of the spectral colours extending from the long-wavelength end of the visible spectrum down to about 530 nm. About a quarter of the number of red-green confusers will be completely unable to distinguish between near-spectral red and yellow stimuli of the same luminance, but this particular confusion should not in general lead to any serious mistakes as a consequence of misinterpreting road traffic-control signal lights. Red-green confusers can be helped to distinguish greens from reds and yellows if the greens have a bluish tinge, but obviously the greens in signal lights should not be so bluish as to perplex people with normal colour vision. About a quarter of the number of red-green confusers are further handicapped by having a reduced sensitivity to red and yellow, that is to spectral colours extending from the long-wavelength end of the visible spectrum down to about 550 nm. This symptom is most severe at the extreme red end of the spectrum, so these people can be substantially assisted to see red signal lights if the chromaticities of the lights are kept close to the yellow limit of the normally acceptable red chromaticity region. In terms of the CIE standard chromaticity diagram, the y coordinate of reds should be greater than 0.290.

It should be noted that red-green confusers do experience other colour confusions, such as partial or total loss of discrimination between whites and bluish greens. In consideration of the difficulties experienced by red-green confusers, there might seem to be some merit in using blue signal lights rather than green ones, but the objections to this proposition are serious : the commonly available light sources have relatively low emission of blue light, and the sensitivity of normal vision is lower to blues than to greens.

2.4.2. Visual acuity

Moderately poor visual acuity does not usually cause problems because road traffic signal lights are fairly large and fairly intense. Nevertheless, poor visual acuity, and excessive scattering of light in the eye as found in elderly people, worsen the recognition of cut-out figures such as arrows and pedestrian symbols. A comprehensive study on the relation between visual acuity, other visual functions and road safety is presented by Davison (1978).

2.4.3. Visual performance

Studies comparing visual ability and driving performance have established that there are significant relationships between certain visual functions and certain indications of driving performance, such as accidents and traffic law violations. Static visual acuity and visual field have only exhibited slight relationships with driving. The correlations are very low although statistically significant. More complex perceptual functions of a dynamic nature, such as dynamic visual acuity, perception of angular movement and movement in depth, and the ability to detect, fixate and identify targets randomly presented in the peripheral field have shown stronger relationships with driving. It is still not clear whether these are useful as predictive instruments (See Davison, 1978).

However, no research has yet been conducted specifically relating any of these visual parameters to the detection and correct interpretation of traffic light signals. From an intuitive standpoint, it can be said that the static acuity, colour vision and contrast sensitivity are the visual functions most likely to be important to signal detection. Increasing the size of the signal light (e.g., from 200 mm to 300 mm), increasing the light intensity to appropriate levels, careful specification of colour boundaries, standardization of signal light positions, adding background screens to provide better figure-to-ground contrast and utilizing the principle of redundancy by using multiple signal heads are all techniques that have been and can be used to counter the effects of moderate reductions in these visual functions.

One of the most important results of recent research into the role of vision in driving, however, is that it has created an awareness of the wide range of visual capabilities to be found among the driving population. Drivers with poor visual acuity, reduced visual fields, inadequate contrast sensitivity, or deficient glare recovery ability can be found on the road. The significance of this is that traffic light signals, as well as all other types of traffic devices, must be designed not for the driver with « average » visual capabilities but, rather, to allow as many drivers as possible to detect and interpret them with an adequate margin of safety.

2.4.4. Flashing lights

Flashing traffic signals may have some merit in traffic control by virtue of their conspicuity. Regularly flashing lights rarely occur in nature, and therefore they may have an increased effectiveness in producing a visual response compared with steady lights. (Crawford, 1962, 1963.)

Flashing light signals for traffic control should be used with discretion. To use such signals for hazard warning in situations where a hazard is obvious (except where there is a regulatory requirement for a flashing light) will eventually lead to the signals falling into disrepute.

Conventional road traffic signals are sometimes used in a flashing mode to give a particular meaning such as a warning or a directive (e.g., flashing red signals at road/rail crossings, flashing yellow or sometimes red signals at junctions are also used in the UK at some signalled pedestrian crossings).

It is to be noted that the « effective » luminous intensity of a flashing light may be significantly less than the maximum luminous intensity reached during the flash. The apparent reduction results from inertial effects in the organ of vision and can be substantial for flash durations of less than a few tenths of a second. On the basis of various investigations (Allard, 1876; Blondel and Rey, 1911; Douglas, 1957; Schmidt-Clausen, 1967, 1969, 1971), several procedures for calculation of effective intensity have been proposed; these lead to very similar results for most practical forms of flash (Reynolds, 1975). Flashing light signals should be designed to provide an « effective » intensity not less than the luminous intensity that would be required from a steady light signal under the same conditions.

This requirement places certain constraints on such parameters as the flashing rate and the on/off ratio, but careful selection will result in improved conspicuity over the expected range of the signals. The possible physiological effect of flashing lights (in the range of 7-12 flashes/second) on persons susceptible to epilepsy should not be overlooked.

The characteristics of the light source must be suitable for the flashing rate and the on/off ratio required. In the case of filament lamps (including tungsten-halogen filament lamps) commonly used for road traffic signals, there is unlikely to be a problem over the range of flashing rates currently used. (Examples of flashing rates in use for red or yellow signals are : UK 72-88 flashes per minute, USA 50-60 flashes per minute, Netherlands 40-60 flashes per minute.)

In relation to the conspicuity of flashing lights, there appears to be at present no scale of values or agreed method of measurement available. The design of flashing lights to give high conspicuity does not necessarily make them convey more information. Flashing lights and their applications are discussed in great detail in the Proceedings of the Flashing Lights Symposium (Anon., 1971), see also Blaise (1976).

A possible way to increase the conspicuity of a conventional traffic signal is to pulse the light, rhythmically varying the luminous intensity between a high and a lower level. In this way the light is not extinguished as in the flashing mode. Apart from the use of pulsating red and yellow (amber) signals in some experimental signals for light-controlled pedestrian crossings in the UK during the early 1960's, no scientific work has been done to assess the conspicuity of pulsating light signals for road traffic control or their possible advantages to road users with defective colour vision.

2.5. FACTORS ADVERSE TO VISIBILITY

The visibility of signal lights is often considerably reduced by atmospheric scatter and absorption. Fog and also falling snow or rain will reduce the visibility. The adverse effects of fog can be counteracted to a certain extent by raising the luminous intensity of the lights. Since in road traffic it is the conspicuity and the recognition of the signals that are significant, it is not clear to what extent the intensity should be raised.

Other causes for impairment of visibility are soiling of and rain on the lenses of the signal lights, and on the windscreens of the vehicles. In addition, many cars have windscreens that are scratched or have deteriorated in other ways. These factors lead to increased light scatter and consequently a decrease in the effective luminous intensity directed towards the driver or observer (Allen, 1974).

Although to a certain extent these adverse factors could be reduced by proper maintenance and cleaning, it is more practical to apply a safety factor to the required luminous intensities to take care of the combined effects of fog, rain, etc. This factor, however, is not usually stated.

Rain not only reduces the visibility of the light signals owing to scatter of the light in the water on the lenses and the windscreens; in addition the road surface becomes wet, which results in an increase of unwanted reflections from its surface, and a reduction of the skidding resistance of the surface (and consequently an increase of the safe stopping distance). Thus, the visual range of the light becomes less under circumstances where it ought to become greater.

All these factors are considered in the determination of the optimum luminous intensity of road traffic signal lights (See Section 4.3.).

2.6. TRAFFIC ENGINEERING

2.6.1. Visual range of signals

Based on the considerations discussed above, it is possible to indicate at what distance a traffic control signal *may* be visible, and at what distance it usually will be seen, be recognized and be interpreted correctly. Another consideration is at what distance the signal *should* be visible. In theory, the answer to this question should be given by the traffic engineer. However, in practice, it is difficult to apply traffic engineering in this way. In particular, it would not be sensible to replace the required visibility distance by the safe stopping distance, although they are in some way related. On the basis of practical experience, it seems that for low speeds the signal should be visible at a distance far longer than this stopping distance, but at higher speeds the difference between these two distances may be smaller. Another consideration is that detection of the signal is not sufficient. Thus, a calculation based only on stopping distance will result in a first approximation only. These considerations have been analyzed in detail in Section 3.5., which is an attempt to develop the photometric requirements of traffic lights on a more rigorous basis than usual.

In several countries a minimum visibility distance of 100 m has been adopted for traffic signals within built-up areas, independent of the actual driving speed and of the local speed limits. Firstly, it is impractical to consider a large number of different types of signals for different situations; and secondly, conditions with respect to maintenance, to the atmosphere and the light and to the driving population may greatly vary. For roads outside built-up areas there is not yet general agreement, although it is understood that on rural roads the visibility distance should be considerably greater than in built-up areas; that on high-speed rural roads usually some sort of pre-warning is necessary; and that on freeways and motorways the conventional types of signals should be avoided.

Not only are the requirements regarding the luminous intensity on the beam axis dependent upon the traffic situation, but other requirements are also. Details regarding the size of the signal light, the spatial light distribution, and the size and shape of figures in the signals are given in other sections of the report.

2.6.2. Intersection design and positioning of signals

The geometric design of intersections and the positioning of traffic signals on the highway are directly related to the visual effectiveness of traffic signals in communicating from the signalling system to the user (Anon, 1977; German Standards DIN 57 832).

The design of traffic islands, and other channelization such as medians and turning lanes, should permit drivers to follow a logical and natural path through an intersection. In doing so, the accompanying traffic signals should be installed along the same approximate path and be aimed to enhance their visibility so that a driver will find a traffic signal in his normal direction of view. This design problem becomes especially critical at a skewed intersection where a wide open space in the centre of the intersection may make driver orientation more difficult. For this application the use of screens, long visors, louvres or narrow-beam traffic signal lights with very sharp cut-offs is often desirable. This last-mentioned signal light is often called an « optically programmed signal », and its light is aimed, and the beam cut-offs are adjusted, so that it is visible only to drivers in the lane(s) for which it is applicable (see Leiser & Paine, 1977).

Properly located channelization provides protection for pedestrians and vehicles and allows pedestrian signals to be located in line with pedestrian crossings. In some cases geometric design features can be used to control speed or to prohibit certain turning movements, in lieu of using traffic signals. In coordinating improved traffic signal location with geometric design features, consideration should be given to the following : approach angles of roads at intersections, sight distance requirements, approach speeds, vehicle demand volumes, traffic mix, intersection widths, positions of pedestrian crossings and stop lines and required turning movements.

The methods used to support traffic signal lights (e.g. posts, gantries, mast-arms or suspension wires) usually depend on the local situation with regard to the road widths, the intersection geometries, the roadside developments, etc., but successive road intersections should look consistent and reasonably uniform to the driver.

Signal lights mounted on posts on the edge of the carriageway are usually easier to install and maintain, especially in congested urban areas. For most situations, satisfactory visibility can be achieved if the height of post-mounted signals is within the range of 2.1 to 4.5 metres, measured from the road to the centre of the lowest optical system. These height limits are desirable to avoid inconvenience to pedestrians and to ensure that signals are not obscured from the view of drivers. Post-mounted signals may be supplemented by overhead signals where the post-mounted signals can be obscured by obstructions.

Overhead signal lights are often desirable when approach speeds are high or where the approach is on a gradient. Typically they should be mounted with the centre of the lowest optical system not less than 4.5 m nor more than 5.7 m above the road surface at the centre of the road. However, once a vehicle has stopped at the stop line, suitably placed curbside signals will be more visible to the driver than overhead installations. Practice indicates that preferably two sets of traffic signal lights should face through traffic on each intersection approach. The design objective is to provide at least one signal which can be seen by the driver at any time (Institute of Traffic Engineers, 1970, 1970a).

For legal reasons, many countries require the positioning of a signal at or near a stop line. A signal in this location is not, however, easily seen by traffic waiting at the stop line, particularly in the outer lanes. An additional signal or signals in front of the driver may be desirable.

In considering appropriate positioning for additional signals, consideration must be given to the driver's « cone of vision ». A cone with a semi-angle of 10° relative to its axis on the line of sight (which is considered as being usually straight ahead) is often taken to indicate the maximum extent of angular deviation which will allow the driver to see the signal and still maintain adequate visual contact with the road and traffic. Hence a calculation can be made, for any position of the driver, of the maximum vertical and horizontal distances that the signal can be offset from the driver's line of sight. An analysis of any signal design plan will then show if proposed locations of signals are within the acceptable range. Post-mounted signals normally remain within the driver's « cone of vision » much longer than do overhead signals.

In this regard, low post-mounted signal lights are superior to overhead signal lights when viewed from the stop line. This assumes that no obstructions, such as parked or moving vehicles, are present. Therefore, it can be concluded that overhead and post-mounted signal lights supplement each other, i.e., overhead provides best long range viewing and post-mounting provides best short range viewing. Furthermore, if sun glare is a problem, the sun will usually not affect both positions of the signal lights at the same time.