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

TECHNICAL REPORT

INTERNATIONAL RECOMMENDATIONS FOR COLOUR VISION REQUIREMENTS FOR TRANSPORT

CIE 143 - 2001

UDC: 612.843.31

Descriptor: Colour vision

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10. De maintenir une liaison et une collaboration technique avec les autres organisations internationales concernées par des sujets relatifs à la science, la technologie, la normalisation et l'art dans les domaines de la lumière et de l'éclairage.

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This Technical Report has been prepared by CIE Technical Committee 4-31 of Division 4 "Lighting and Signalling for Transport" and has been approved by the Board of Administration of the Commission Internationale de l'Eclairage for study and application. The document reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by the CIE membership and other interested parties. It should be noted, however, that the status of this document is advisory and not mandatory. The latest CIE proceedings or CIE NEWS should be consulted regarding possible subsequent amendments.

Ce rapport technique a été préparé par le Comité Technique CIE 4-31 de la Division 4 "Eclairage et signalisation pour les transports" et a été approuvé par le Bureau de la Commission Internationale de l'Eclairage pour étude et application. Le document traite des connaissances courantes et de l'expérience dans le domaine spécifique décrit de la lumière et de l'éclairage; il est destiné à être utilisé par les membres de la CIE et tous les intéressés. Il faut cependant noter que ce document est indicatif et non obligatoire. Les derniers comptes rendus de la CIE ou du CIE NEWS devront être consultés pour connaître d'éventuels amendements.

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FOREWORD

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INTERNATIONAL RECOMMENDATIONS FOR COLOUR VISION REQUIREMENTS FOR TRANSPORT

SUMMARY

This technical report prepared by CIE Technical Committee 4-31 of Division 4 "Lighting and Signalling for Transport" details the official CIE Recommendations for requirements of colour vision that are necessary to ensure safe and reliable recognition of coloured signal lights and other colour coded visual information devices.

The aim of the report is to encourage international harmonisation in colour vision requirements in maritime, air, rail and road transport, and the use of valid methods for the assessment of colour vision.

The recommendations take into account the complexity of the colour codes used, the observation conditions likely to be encountered and the importance of colour recognition to safety in the various transport modes. The report summarises the studies that document the kind of difficulties experienced by persons with defective colour vision and the studies that show defective colour vision is a risk factor.

The report defines three colour vision standards, (1) normal colour vision, (2) defective colour vision A where those with a mild colour vision deficiency can demonstrate their ability to see and recognise coloured signal lights, and (3) defective colour vision B where those with defective colour vision can demonstrate their ability to recognise surface colour codes at a short distance, such as those used on colour coded computer screens.

The report also recommends test procedures for the assessment of colour vision. Detailed information on the recommended colour vision tests is given in an appendix.

RECOMMANDATIONS INTERNATIONALES RELATIVES AUX EXIGENCES DE VISION DES COULEURS POUR LES TRANSPORTS

RESUME

Ce rapport technique préparé par le Comité Technique 4-31 de la Division 4 de la CIE (Eclairage et Signalisation pour les Transports) expose en détail les recommandations officielles de la CIE relatives aux exigences de vision des couleurs nécessaires pour assurer la reconnaissance sûre et fiable des feux de signalisation colorés et des autres dispositifs d'informations visuelles colorés.

Le but du rapport est de proposer une harmonisation internationale des exigences de vision des couleurs pour les transports maritimes, aériens, ferroviaires et routiers, et l'utilisation de méthodes valables pour l'estimation de la vision des couleurs.

Les recommandations prennent en compte la complexité des codes colorés utilisés, les conditions d'observation susceptibles d'être rencontrées et l'importance de la reconnaissance des couleurs pour la sécurité des différents modes de transport.

Le rapport résume les études qui montrent les types de difficultés rencontrées par les personnes possédant une vision des couleurs déficiente et les études qui montrent qu'une vision des couleurs déficiente est un facteur de risque.

Le rapport définit trois types de vision des couleurs, (1) vision des couleurs normale, (2) vision des couleurs déficiente A correspondant aux personnes présentant une déficience légère et pouvant prouver leur capacité à voir et reconnaître les feux de signalisation colorés, et (3) vision des couleurs déficiente B correspondant aux personnes présentant une déficience et pouvant prouver leur capacité à reconnaître les codes colorés à faible distance, tels que ceux utilisés sur écrans d'ordinateurs.

Le rapport propose également des procédures d'essais pour l'évaluation de la vision des couleurs. Des informations détaillées sur les essais recommandés sont données en annexe.

INTERNATIONALE EMPFEHLUNGEN FÜR ANFORDERUNGEN AN DAS FARBSEHVERMÖGEN IM VERKEHR

ZUSAMMENFASSUNG

Dieser Technische Bericht wurde vom Technischen Komitee 4-31 der CIE-Division 4 "Beleuchtung und Signale für den Verkehr" ausgearbeitet und präzisiert die offiziellen Empfehlungen der CIE für Anforderungen an das Farbsehvermögen, um sicheres und zuverlässiges Erkennen von farbigen Signallichtern und anderen Einrichtungen mit farbkodierten visuellen Informationen zu gewährleisten.

Dieser Bericht hat zum Ziel, die internationale Harmonisierung der Anforderungen an das Farbsehvermögen im See-, Flug-, Zug- und Straßenverkehr sowie die Anwendung geeigneter Methoden für die Beurteilung des Farbsehvermögens zu fördern.

Die Empfehlungen berücksichtigen die Vielfalt der verwendeten Farbkodes, die zu erwartenden Beobachtungsbedingungen und die Bedeutung der Farberkennung für die Sicherheit in verschiedenen Transportarten. Der Bericht faßt Studien zusammen, die die Schwierigkeiten von Personen mit mangelhaftem Farbsehen dokumentieren, und Studien, die zeigen, daß mangelhaftes Farbsehen ein Risikofaktor ist.

Der Bericht definiert drei Arten von Farbsehen:

- (1) normales Farbsehen,
- (2) anomales Farbsehen A, bei dem Personen mit leichter Farbenfehlsichtigkeit farbige Signalleuchten sehen und erkennen können, und
- (3) anomales Farbsehen B, bei dem Personen mit anomalem Farbsehen farbige Oberflächenkodes, wie farbkodierte Computerbildschirme, auf kurze Entfernung erkennen können.

Der Bericht empfiehlt ferner Testverfahren zur Beurteilung des Farbsehens. Details über die empfohlenen Farbsehtests werden in einem Anhang aufgeführt.

1. INTRODUCTION

It has long been recognised that people with defective colour vision have difficulty recognising the colours of signal lights and that this may pose a risk of accident in sea, rail, road and air transport. The first colour vision standards were introduced by maritime regulatory authorities and railway companies in 1877. The aviation colour vision standard was first adopted in 1919 (Vingrys and Cole, 1986).

Although there are some broad international agreements on colour vision standards, there are considerable differences between countries as to how the standards should be defined, how colour vision should be assessed for the purpose of testing against the standards and what the fail criteria should be.

Since transportation is international it is very desirable that there be harmonisation between countries on the colour vision standards adopted for each transport modality, and uniformity in the way they are implemented.

This Report sets out recommendations for colour vision requirements for maritime, rail, road and air transport in order to encourage international harmonisation.

2. DEFECTIVE COLOUR VISION

Defective colour vision is common. Congenital colour vision deficiency affects approximately 8% of men and 0,4% of women.

Congenital colour vision deficiency is an inherited defect of vision that is present at birth and which remains unchanged throughout life. A smaller number of people have an acquired colour vision defect that can arise as a result of ocular disease or some medications.

There are 9 different types of congenital colour vision deficiency which vary considerably in severity from total colour blindness to a defect so mild that there may be little effect on colour recognition.

The different types of congenital colour vision deficiency are described in Table 1.

Normal colour vision is mediated by three cone receptor systems in the retina of the eye. The cone receptors of each of the three systems contain a photopigment unique to that system. The photopigment of one cone system responds maximally to long wavelength light, to middle wavelength light in the second cone system and to short wavelength light in the third. These three receptor systems are described as the L, M and S cones respectively. In the past they were called the red, green and blue cones. In congenital colour vision deficiency there is an anomaly of one or more of the cone photopigments.

In some types of defective colour vision one receptor photopigment is missing. In other types, one of the three receptors has an abnormal photopigment replacing the normal photopigment. In some rarely occurring forms of defective colour vision two or all three normal photopigments are missing.

2.1 Congenital colour vision deficiency

Congenital colour vision deficiency is classified according to the number and type of photopigment that is missing or is abnormal (Table 1).

2.1.1 Monochromasy

In monochromasy there is only one cone pigment instead of three. In the most commonly occurring form of monochromasy, the one cone pigment is rhodopsin, the same pigment that is found in the rod (night vision) receptors of the retina. In another form of monochromasy, the single cone photopigment is the S (or blue) photopigment. People with monochromasy are totally colour blind because they have only one colour receptor system instead of three.

Monochromasy is very rare and is almost always associated with loss of visual acuity. Such people are unlikely to seek responsible employment in the transport industries because of their reduced visual acuity and their profound inability to recognise colours.

Table 1. Types of congenital defective colour vision

Classification	Prevalence ³	Mechanism	Characteristics
Monochromasy			
Typical mono-chromasy	rare	No normal photopigments.	Colour blind. Colours distinguished by brightness differences only. Very insensitive to red light. Nystagmus. Low visual acuity 6/36 to 6/60. Painless photophobia.
Blue cone mono-chromasy	rare	S (blue) cone pigment only. No L (red) or M (green) cone pigment	Colour blind. Colours distinguished by brightness differences only. Very insensitive to red light. Nystagmus. Low visual acuity 6/12 to 6/24. Painless photophobia.
Atypical mono-chromasy	very rare	Mechanism unknown	Colour blind. Colours distinguished by brightness differences only. Insensitive to red light. Normal visual acuity. No nystagmus.
Dichromasy			
Protanopia ¹	1% of men 0,01% women	Absence of L(red) cone pigment	Very reduced ability to identify colours. Confuse red, yellow and green, white and green, black and red. Reduced sensitivity to red light.
Deuteranopia	1% of men 0,01% women	Absence of M (green) cone pigment	Very reduced ability to identify colours. Confuse red, yellow and green, and white and green.
Tritanopia	1 in 13000 both men & women	Absence of S (blue) cone pigment	Very reduced ability to identify colours. Confuse blue, blue green and green, and white and yellow.
Anomalous Trichromasy			
Protanomaly	1% of men 0,03% women	L (Red) cone pigment maximum absorption shifted to shorter wavelengths of light	May confuse white with green and confuse reds, yellows and greens but loss of colour discrimination varies greatly between individuals. Reduced sensitivity to red light. Make abnormal colour matches: for example will add excess red in the colour match $R + G = Y$
Deuteranomaly	5% of men 0,35% women	M (Green) cone pigment absorption shifted to longer wavelengths of light	May confuse white with green and confuse reds, yellows and greens but loss of colour discrimination varies greatly between individuals. Make abnormal colour matches: for example will add excess green in the colour match $R + G = Y$
Tritanomaly ²	rare	Partial loss of S cone pigment	Loss of colour discrimination for blues, blue-greens, and greens

1 Protanomaly and protanopia are collectively referred to as Protan colour vision defects, and deuteranomaly and deuteranopia are referred to as Deutan defects. Protan and deutan colour vision defects are often collectively described as red-green defects.

Tritanopia and tritanomaly are often described as the Tritan or blue-green colour vision defects.

2 Tritanomaly is probably a partially expressed form of tritanopia rather than a separate kind of abnormal colour vision, (Cole, Henry and Nathan, 1966).

3 The prevalences quoted are for Caucasians. The prevalence of colour vision deficiencies are generally lower for other races.

2.1.2 Dichromasy

There are three types of colour vision deficiency which result from a lack of one of the three colour photopigments. Because there are only two effective colour receptor systems these defects are known collectively as dichromasy. About 2% of men and 0,02% of women have dichromasy.

People who have dichromatic colour vision have a very substantial loss of colour vision.

The two most commonly occurring forms, protanopia and deuteranopia, are characterised by an inability to reliably differentiate red, yellow and yellowish-green, and white and green.

Protanopia results from a lack of the 'red' (L) photopigment, and deuteranopia results from the lack of the 'green' (M) photopigment.

Their inability to reliably recognise red, yellow, green and white means that they will make errors recognising signal colours used in all forms of transport.

Because protanopia is due to the loss of the long wavelength (red) photopigment in the retina protanopes also have a very reduced ability to see red lights. Red signals appear less bright to them and the distance from which they can see red signals may be up to 40% less than that of persons with normal colour vision (Cole and Vingrys, 1983b; Verriest et al., 1980). They may also confuse red and white signals (Cole and Maddocks, 1995) and may confuse red and black surface colour codes.

The third kind of dichromasy is tritanopia that is the result of a lack of the 'blue' photopigment. Tritanopes are relatively rare and because they can distinguish red, yellow, green and white are of less importance to safety in transport. They confuse blues and greens, and white and yellow.

2.1.3 Anomalous trichromasy

There are three other types of colour vision deficiency in which one of the three photopigments is anomalous. This class of defective colour vision is known as anomalous trichromasy. The loss of ability to distinguish colours in anomalous trichromasy can vary considerably from a defect almost as severe as dichromasy to one so mild that it has few practical consequences.

Nevertheless, nearly half of anomalous trichromats will have difficulty recognising signal colours (Vingrys and Cole, 1983; 1993). In addition, it must be noted that the form of anomalous trichromasy resulting from an anomalous red receptor, protanomaly, is characterised, like protanopia, by a very greatly reduced ability to see red light. (Cole and Vingrys, 1983b; Kinnear, 1986)

2.2 Acquired colour vision defects

In addition to the inherited colour deficiencies, colour vision defects can be acquired as a result of a disease of the retina, the optic nerve or visual pathways. Some medications can also disturb the colour sense. These disturbances of colour vision will occur less often than the congenital inherited colour vision deficiencies because ocular diseases are not very common. Moreover, many ocular diseases are age related so that ocular diseases causing a colour vision deficiency will most commonly occur after retirement from active work. Nevertheless, colour vision deficiencies due to ocular disease and medical treatments do arise during a working life, sometimes at a relatively young age. Many ocular diseases cause a tritan (blue-yellow) colour vision deficiency which may not greatly affect the ability to recognise work place colour codes but the retinal dystrophies and optic nerve atrophies can cause a red-green colour vision deficiency. All acquired colour vision deficiencies can progress to colour blindness.

Authorities responsible for ensuring that key personnel in the transport industries continue to have good vision during their working career should be alert to the possibility that ocular disease and medications can reduce the ability to distinguish colours. Whenever, a key

transport operator is found to have an ocular disease or is under continuing medication, the possibility of an acquired colour vision loss should be investigated.

Birch (Birch, 1993) provides a good summary of the acquired colour vision deficiencies.

2.3 The practical difficulties experienced by people with defective colour vision

Laboratory and field investigations have shown that people with colour deficiencies make errors identifying signal colours (Vingrys and Cole, 1988). They are also slower in responding to signal lights (Nathan et al., 1964; Cole and Brown, 1966) and in acquiring information from colour coded electronic visual displays (Cole and Macdonald, 1988).

Steward and Cole (Steward and Cole, 1989) give an account of the personal experiences of people with defective colour vision. They administered an exhaustive questionnaire to 100 persons with defective colour vision and to a control group of equal size that had normal colour vision under conditions that would encourage frank responses.

Table 2 summarises the percentage of persons with abnormal colour vision who reported practical difficulties with colour in this study. The control group with normal colour vision never reported any problems.

Between one quarter and one third of colour vision defectives reported difficulty distinguishing road traffic light colours or confusing them with street lights. A smaller proportion had difficulty seeing vehicle brake lights. Those with more severe colour vision defects were more likely to report difficulty with road traffic lights with about half of dichromats reporting this problem.

In collecting these responses, care was taken only to record serious and commonly occurring problems with colour. Reports of occasional or transitory problems with colour were not recorded as difficulties.

Interestingly the study showed that 5% of dichromats and 25% of adult anomalous trichromats were unaware of their defect until their colour vision was tested on entry into the study. This might suggest that their colour vision defect was so mild as to be of no practical consequence. However, only 7% of the colour vision defective subjects reported no practical problems with colour (Cole and Steward, 1997).

Since people with the more severe forms of defective colour vision can have a very substantially reduced ability to differentiate colours it might be thought that they would avoid occupations that involve colour recognition. If this were the case then there would be no need for occupational colour vision requirements and colour vision testing.

However, most people with defective colour vision do not have a realistic appreciation of the extent to which their ability to recognise colours is impaired. This is probably because they have never experienced the normal perceptions of colour and because of an unwillingness to acknowledge that they have an impairment.

A further difficulty in assessing the practical handicap of defective colour vision is that persons with defective colour vision, who are unable to recognise colour codes, can often make use of redundant cues. For example, road traffic signal lights may be correctly interpreted on most occasions by the position of the traffic signal that is illuminated, or the relative brightness of the different colours, or by the movement of other traffic, all of which can provide non-colour cues to the colour of the traffic light illuminated. This means that people with abnormal colour vision are often able to compensate for their inability to differentiate colour. However, there is clearly a risk of error when, for some reason or other, the redundant cues are not available or are misleading.

It cannot be assumed that persons with defective colour vision will have a good appreciation of their handicap and that they will voluntarily decide not to seek training or employment in occupations requiring colour recognition. Table 2 shows that about a quarter of people with defective colour vision are in work or have been in work where they experienced difficulty with colour.

Table 2. Percent colour vision deficient subjects reporting difficulty with colour*

Task or activity	% reporting difficulty
Driving	
Distinguishing traffic signal colours	29
Confusing street lights with traffic lights	26
Difficulty seeing brake lights	13
Difficulty reading road signs	9
Occupational	
Defective colour vision affected career choice	34
Difficulty with colour experienced at present work	25
Difficulty with colour at work in previous jobs	23
Every day activities	
Selecting coloured goods (clothes, paints, interior decoration items, cosmetics, etc)	74
Working at crafts or hobbies (colours of wires, threads, wools, paints, etc)	39

* Data from Steward and Cole (Steward and Cole, 1989). Table adapted from Cole and Steward (Cole and Steward, 1997)

3. GENERAL PRINCIPLES OF SETTING COLOUR VISION REQUIREMENTS

Rail, sea and air transport authorities have colour vision requirements because of the need to recognise the colours of signal lights. Persons with colour vision deficiency are known to confuse signal colours and respond more slowly to them with a consequent risk of accident. They are also slower and make more errors interpreting colour coded electronic visual displays that are now used in aircraft and for air and rail traffic control.

In setting standards that have the effect of excluding some people from employment or from holding the privileges of a licence, care must be taken to ensure that there is sufficient evidence to show that there is real community benefit from doing so, through enhanced safety.

If such evidence exists, then the best first step is to explore the possibility of engineering changes so that colour is not so important or so that the colours used can be recognised by persons with colour vision deficiencies.

This is often not possible and it is necessary to have a colour vision requirement. The requirement must be defined in a way that does not unfairly exclude those with colour vision deficiency who in fact can safely recognise the colours used. Technically it would be relatively easy to exclude all persons with defective colour vision from critical positions in transport. The test methods for the detection of abnormal colour vision are inexpensive, reliable and simple to administer. However, this simple approach would be unfair because some forms of colour vision deficiency are so mild as not to impair the ability to recognise signal colours and colour codes.

3.1 Avoiding the need for a colour vision requirement by ergonomic engineering

In the interests of equality of opportunity, every effort should be made to avoid the need to exclude people because of a physical impairment. Efforts should always first be directed to ergonomic engineering changes. In the case of colour vision defects, ergonomic design should endeavour to reduce dependence on the need to recognise colour, or to design the colour signal or colour code system so that it is recognisable by all or most people with defective colour vision.

The principles of good engineering for colour codes are:

1 The number of colours in the code should be kept to a minimum

Persons with dichromasy or severe anomalous trichromasy cannot reliably identify a categorical signal colour code with more than two colours (Heath and Schmidt, 1959). The greater the number of colours in the colour code system the more likely it is that persons with defective colour vision will make errors in colour identification. Even though in everyday judgements they can name and differentiate a score or more of surface colours they do so in part because of brightness rather than colour differences and their reliability in naming colours is very much less than that of persons with normal colour vision. Dichromats can, at best, see only three signal colours, yellow, white and blue, but will be uncertain in doing so because they confuse red with yellow and white with green.

2 The colours must be those that are most easily recognisable

The CIE has provided guidance on the signal and surface colours that are the most recognisable (CIE, 1983; 1994; 2001). Many National Standards have based their specification of the colours of signal and surface colour codes on the recommendations of the CIE.

3 The colours selected should be those that are least likely to be confused with other colours by users with colour vision deficiency

Within the CIE recommended colours, there are colours that are less likely to be confused by persons with colour vision deficiency. The CIE (CIE, 1994; 2001) provides guidance on this. Blue is a good colour to include in a colour code that is to be used by persons with defective colour vision since blue is not confused by them with other colours. However, even when blue is included in a colour signal code, errors are still made by persons with defective colour vision except for large and bright signals (Sloan and Habel, 1955a; 1955b). Vingrys and Cole (Vingrys and Cole, 1992) showed that even with a carefully selected set of red, green and white signals of small angular subtense, persons with defective colour vision still made a large number of errors.

4 Red signal lights should have an intensity that will enable a person with a protan colour vision deficiency to see the red signal at a safe distance

There are recommendations for the minimum intensity of red signal lights such that protan users of the signal system will be able to see the red signal at a reasonably safe distance (Cole and Brown, 1966; CIE, 1980).

5 There should be redundancy whenever it is practical

Engineers should always include redundancy as a matter of good ergonomic design, but to do so is even more important when the user group includes persons with defective colour vision. The redundancy may be provided by alphanumeric identification, position (e.g. red at the top of the signal array), shape, size (e.g. the red signal larger) number (e.g. two red signals) or brightness differences. Redundant shape coding has often been proposed for road traffic signals. However, vignetting to produce a shape can reduce the light output of a signal and shape is not useful at long observation distances because the shape cannot be recognised.

However, there are limitations to what can be achieved by good engineering and good ergonomics. Even good ergonomic engineering cannot meet the needs of all persons with colour vision deficiency. There are also practical constraints. For example, a change from colour signals to some other means of visual communication that does not use colour would not be readily accepted. The colours red, green, yellow and white are the community accepted colour codes in transport and international agreement to substitute other colours is highly unlikely. Transport is often international and strict adherence to best ergonomic practice in every port or every airfield in every country would be difficult to achieve.

Colour coding is an integral part of the design of visual communication systems and its value in visual communication has been conclusively shown (Christ, 1975). With increasing system complexity its use is increasing rather than decreasing. Signal lights for visual communication over distance, in use for hundreds of years, remain in wide use despite the technological revolution that provides alternative means of communication and control of transport. In fact, the technological revolution has increased the use of colour coding in control

and instrument panels and in computer displays. Colour coding is now ubiquitous for the delineation and visual organisation of complex visual displays, be it in computer screens, industrial control panels or to define navigable routes on roads, in sea ports and on airfields. These colour codes often have to be recognised under conditions of low lighting at night or under conditions where visibility is impaired by poor weather.

3.2 Principles for setting colour vision requirements

In defining the recommended colour vision requirements described in the sections below, account has been taken of the following points:

1. the extent to which coloured signals and codes are used in the various modes of transport and the importance of those signals and colour codes to safe operation.
2. the evidence showing that persons with defective colour vision are unable to recognise the signal colours and colour codes used and the evidence that there is an increased risk of accident through an inability to recognise signal colours.
3. the costs of accident and community expectations of standards of safety.

More stringent colour vision standards are recommended when the social, environmental and economic costs of accidents are high and when the community expects the highest standards of safety to be implemented. This involves a balanced judgement between risks to the community and the rights of individuals to be professionally employed in a transport industry.

Accordingly, a rigorous colour vision requirement is recommended for professional airline pilots but a less rigorous requirement for private pilots. Likewise, a colour vision requirement is recommended for professional drivers of trucks, buses and taxis but a requirement is not recommended for private drivers of motor cars who drive less and whose vehicles, when involved in accident, will normally cause less social and economic damage than larger vehicles or passenger carrying vehicles.

4. the availability of reliable and valid test methods.

The recommended colour vision requirements must take account of the test methods that are available and their reliability. This is essential for fairness since unreliable or invalid test methods may fail persons who are capable and pass those who are not. Care has been taken in these recommendations in the choice of test methods and to carefully define the procedures and pass/fail criteria for testing colour vision so that there can be consistency in testing.