ISBN 978 3 901 906 61 9

CIE

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

TECHNICAL
REPORT

ROAD TRANSPORT LIGHTING FOR DEVELOPING COUNTRIES

CIE 180:2007

UDC:	628.971	Descriptor:	Exterior lighting
	628.971.6		Street lighting

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The International Commission on Illumination (CIE) is an organisation devoted to international co-operation and exchange of information among its member countries on all matters relating to the art and science of lighting. Its membership consists of the National Committees in about 40 countries.

The objectives of the CIE are :

1. To provide an international forum for the discussion of all matters relating to the science, technology and art in the fields of light and lighting and for the interchange of information in these fields between countries.
2. To develop basic standards and procedures of metrology in the fields of light and lighting.
3. To provide guidance in the application of principles and procedures in the development of international and national standards in the fields of light and lighting.
4. To prepare and publish standards, reports and other publications concerned with all matters relating to the science, technology and art in the fields of light and lighting.
5. To maintain liaison and technical interaction with other international organisations concerned with matters related to the science, technology, standardisation and art in the fields of light and lighting.

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2. D'élaborer des normes et des méthodes de base pour la métrologie dans les domaines de la lumière et de l'éclairage.
3. De donner des directives pour l'application des principes et des méthodes d'élaboration de normes internationales et nationales dans les domaines de la lumière et de l'éclairage.
4. De préparer et publier des normes, rapports et autres textes, concernant toutes matières relatives à la science, la technologie et l'art dans les domaines de la lumière et de l'éclairage.
5. 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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2. Grundnormen und Verfahren der Meßtechnik auf dem Gebiet der Lichttechnik zu entwickeln.
3. Richtlinien für die Anwendung von Prinzipien und Vorgängen in der Entwicklung internationaler und nationaler Normen auf dem Gebiet der Lichttechnik zu erstellen.
4. Normen, Berichte und andere Publikationen zu erstellen und zu veröffentlichen, die alle Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik betreffen.
5. Liaison und technische Zusammenarbeit mit anderen internationalen Organisationen zu unterhalten, die mit Fragen der Wissenschaft, Technik, Normung und Kunst auf dem Gebiet der Lichttechnik zu tun haben.

Die Arbeit der CIE wird in 7 Divisionen, jede mit etwa 20 Technischen Komitees, geleistet. Diese Arbeit betrifft Gebiete mit grundlegendem Inhalt bis zu allen Arten der Lichtanwendung. Die Normen und Technischen Berichte, die von diesen international zusammengesetzten Divisionen ausgearbeitet werden, sind von der ganzen Welt anerkannt.

Tagungen werden alle vier Jahre abgehalten, in der die Arbeiten der Divisionen überprüft und berichtet und neue Pläne für die Zukunft ausgearbeitet werden. Die CIE wird als höchste Autorität für alle Aspekte des Lichtes und der Beleuchtung angesehen. Auf diese Weise unterhält sie eine bedeutende Stellung unter den internationalen Organisationen.

Published by the

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Street lighting

The following members of TC 4-37, "Road transport lighting for developing countries" took part in the preparation of this technical report. The committee comes under Division 4 "Lighting and Signalling for Transport".

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ROAD TRANSPORT LIGHTING FOR DEVELOPING COUNTRIES

SUMMARY

The great majority of the deaths from road accidents happen in the less-motorised developing regions of the world, particularly Asia - and the absolute numbers are growing. As in the highly motorised countries of the world, a significant proportion of accidents occur at night. This report deals with the part that better lighting and visibility can play in reducing the toll of death and injury; it is addressed to those involved in road safety work, not to lighting specialists. Its basic intentions are to guide, inform and encourage.

The report starts by explaining the basic "language of light" and defining the terms and quantities it uses. The night-time value of simple road markings and signs is then explained, stressing the importance of retroreflective materials. This leads to the role of vehicle lighting, with particular emphasis on the need for individual drivers to take responsibility for cleaning and aiming. A chapter on fixed roadway lighting deals with the basic design of simple installations and explains the many different factors that need to be considered. Because of its importance, maintenance is considered in a separate chapter. Finally, there is some general lighting-related material for use in road safety campaigns.

A consistent message of the report is that it is worth doing something rather than nothing, as long as it is done intelligently and with an understanding of the basic principles involved.

ECLAIRAGE ROUTIER POUR LES PAYS EN VOIE DE DEVELOPPEMENT

RESUME

La grande majorité des décès dus aux accidents de la route ont lieu dans les régions du monde en développement les moins motorisées, surtout en Asie – et leur nombre ne cesse d'augmenter. Comme dans les pays du monde fortement motorisés, une grande proportion des accidents ont lieu la nuit. Ce rapport montre qu'un bon éclairage et une bonne visibilité peuvent jouer sur la réduction du nombre de morts et de blessés; il s'adresse aux personnes concernées par la sécurité routière, et non aux spécialistes de l'éclairage. Ses buts principaux sont de les guider, les informer et les encourager.

Le rapport commence par des explications sur le « langage de la lumière" et les définitions des termes et des quantités utilisés. Il explique l'avantage pendant la nuit des simples marquages et signaux routiers, en insistant sur l'importance des matériaux rétro réfléchissants. Cela conduit au rôle de l'éclairage propre des véhicules, en insistant sur la nécessité pour les conducteurs d'assurer leur nettoyage et leur réglage. Un chapitre sur l'éclairage routier traite des études d'installations de base et détaille les multiples facteurs à prendre en compte. Du fait de son importance, la maintenance est traitée dans un chapitre spécifique. Enfin, en annexe sont donnés des conseils relatifs à l'éclairage général pour mener des campagnes sur la sécurité routière.

Le message essentiel de ce rapport est qu'il vaut mieux faire quelque chose plutôt que rien du tout, à partir du moment où on le fait de façon intelligente et avec une bonne compréhension des principes de base concernés.

STRASSENBELEUCHTUNG IN ENTWICKLUNGSLÄNDERN

ZUSAMMENFASSUNG

Die meisten Verkehrsunfälle mit tödlichem Ausgang passieren in den weniger motorisierten Teilen der Erde, in Entwicklungsländern, und hier besonders in Asien – und die absolute Zahl ist im Steigen. Wie in den hochmotorisierten Ländern findet ein wesentlicher Teil der Unfälle bei Nacht statt. Dieser Bericht beschäftigt sich mit besserer Beleuchtung und Sichtbarkeit und ihrer Rolle in der Verminderung der Zahl der Verkehrsopfer. Er richtet sich an Experten für

Verkehrssicherheit und nicht an Strassenbeleuchtungsspezialisten und möchte vor allem anleiten, informieren und ermutigen.

Der Bericht beginnt mit der Bedeutung des Lichtes oder auch der „Sprache des Lichts“ und mit den Definitionen der verwendeten Ausdrücke und Einheiten. Die Wirksamkeit von einfachen Strassenmarkierungen und -zeichen während der Nacht, wird ebenso erklärt, wie die Wichtigkeit von rückstrahlenden Materialien. Danach wird übergeleitet zur Rolle der Fahrzeugbeleuchtung mit besonderer Betonung der individuellen Verantwortung des Fahrers, diese zu reinigen und einzustellen. Ein Kapitel über feste Strassenbeleuchtung nimmt sich der Planung einfacher Anlagen an und erklärt die vielen unterschiedliche Faktoren, die berücksichtigt werden sollten. Wegen ihrer Bedeutung wird die Instandhaltung in einem separaten Kapitel behandelt. Zum Schluss sind einige allgemeine Materialen angeführt, die für Kampagnen zur Erhöhung der Strassensicherheit verwendet werden können.

Die durchgängige Botschaft des Berichtes ist, dass wenig tun deutlich besser als nichts tun ist, solange grundlegende Zusammenhänge beachtet werden.

PREFACE

This document has been written to help reduce the growing number of deaths and injuries in developing countries caused by road accidents. More specifically, it is concerned with ways of improving night-time visibility, and hence night-time road safety.

Road safety programmes demand the efforts of a wide range of people, with different skills and specialisations. The topics in the following chapters will be of interest to a similarly wide range of disciplines. For example, the chapters on roadway signs and markings, and fixed roadway (public) lighting, will be of most relevance to the highway engineer. The chapter on vehicle lighting will be more appropriate for officials concerned with vehicle standards and road-worthiness. The appendix listing points of good practice for the general public will help those responsible for compiling "Highway Codes" or running safety campaigns.

The contents have been written for the technically-literate engineer or decision-maker who can influence activity in any of the areas covered. It should also prove useful to policy-makers in donor countries and organisations who are concerned with road safety technical assistance. It has not been written for the lighting professional, who will (or should) already be familiar with its contents.

In compiling this report much time was spent trying to define the term "developing country". Out of context this proved a futile exercise. Suffice it to say that the content is geared towards the lower end of the developing country spectrum, in terms of gross national product, and is aimed more at rural areas and small towns than at the major cities, where there will usually be more financial and technical capability. If the reader recognises something of his/her situation in the remarks in the following introduction, then it is hoped that what follows will be of relevance and some value.

A recurring theme in the manual is that it is possible to make some improvements even when resources are tightly stretched, and when the ideal from the point of view of international standards seems unattainable. The stance taken is that "something is better than nothing" - as long as it is done properly and with understanding of the fundamental principles at work. To assist with this, a chapter on the basics of lighting is included. This should improve understanding, not least of the technical jargon involved, and give the non-specialist confidence to experiment and improvise.

The information presented here has drawn on many sources, and on the collective wisdom of CIE Technical Committee 4-37. Thanks are due to the members of that committee who contributed their time and expertise, and assisted in shaping the contents of the final document.

J Stuart Yerrell
Chairman TC 4-37

1. INTRODUCTION

1.1 Road safety worldwide

A global survey of road safety made at the turn of the century has estimated that between 750 and 880 thousand people die each year in road accidents, and that between 23 and 34 million are injured. Only 14% of these deaths take place in the highly motorised countries of the world in Europe, North America and Japan. The great majority, some 86%, occur outside these regions, with Asia accounting for nearly half the total.

Region	Fatalities (%)	Vehicles (%)	Population (%)
Highly motorised	14	60	15
Asia/Pacific	44	16	54
Central/E. Europe	12	6	7
Latin America/Caribbean	13	14	8
Sub-Saharan Africa	11	4	11
M East/N Africa	6	2	4

This broad picture is consistent with a more detailed country-by-country analysis, where the records permit. High rates of fatalities per vehicle are linked with low vehicle ownership in the poorer countries, and low rates with the high vehicle ownership levels of the richer industrialised countries. The number of deaths relative to population is much more stable, being of the order of one death per year for every ten thousand people. The middle-ranking countries face the worst on this measure, having rates typically double those of the poorest and the richest countries.

In general, accident numbers are still climbing in the developing countries, although not as dramatically as in the last few decades, and numbers are falling in the industrialised countries. Overall, the total is still rising, with predictions of 1,0 to 1,1 million fatalities per year by the year 2010, and between 1,0 and 1,3 million by 2020. As now, the greatest burden will fall on the developing countries.

1.2 Road safety at night

Where statistics are available from developing countries, it appears that their night-time accidents account for about 30% of the total, a figure similar to the more motorised countries and large enough to merit special attention.

Country	Day (%)	Night-lit (%)	Night-unlit (%)
Shanghai 2000 - All accidents *	67,2	24,0	3,5
Shanghai 2000 - Fatalities	61,4	22,6	16,0
Bangladesh 1998 - All accidents	70,7	22,2	7,1
Bangladesh 1998 - Fatalities	69,9	21,6	8,5
Zimbabwe 1998 - All accidents	66,6	19,5	13,9
Zimbabwe 1998 - Fatalities	50,3	21,5	28,2
Botswana ‘94-95 - All accidents	62,4	12,3	25,3
Botswana ‘94-95 - Fatalities	57,5	10,6	32,0
Botswana ‘94-95 - All accidents, village and rural only	55,1	8,1	36,9
Fiji 2000 - All accidents	72,1	6,6	21,3

* 5,4% of accidents in Shanghai are unattributed and minor. For Bangladesh, dawn and dusk accidents have been added to the "lit" category. For Botswana, "moonlight" has been added to the "unlit"' category.

These figures also show that night-time accidents are, on average, more severe - the percentage of fatalities increases at night. This is particularly marked in Zimbabwe and Botswana, which also have most of their night-time accidents on unlit roads. Even in the urban environment of Shanghai, the proportion of deaths and injuries are higher at night: pro rata there are five times as many fatal accidents on the unlit roads there at night than on the same roads in daylight. The authorities in Thailand report night-time accident rates on the Bangkok freeways to be four times as great as during the day. This gives a measure of the need, and the potential value, of improving night-time driving conditions in such countries.

Of course, there is far more to night-time accidents than just poor visibility. Generally speaking, drivers are more tired, younger and less experienced, and are more likely to have been drinking. But darkness conspires with all these factors to increase the risk of misjudgement. The conscientious driver needs all the help that the transport highway engineers and vehicle engineers can provide. Even in broad daylight, consistently good driving is a demanding task, and the onset of darkness increases those demands. The familiar landmarks and features of the road change or disappear. The distance ahead that can be seen with confidence is dramatically reduced, particularly when there is glare from oncoming traffic. Pedestrians and road users without lights can quickly be lost in the shadows.

Any improvements to the visibility of the road, its features, the vehicles on it - including pedestrians, cyclists, animals and carts - is likely to improve the overall accident record.

1.3 Application and modification of recommendations

The basic processes of seeing and perceiving are universal. Human eyes respond to different lighting levels the same the world over. But the technologies and standards of night-time driving have been developed largely in the highly motorised and relatively wealthy industrialised countries. The recommendations of the International Commission on Illumination (CIE) are geared to the conditions in the industrialised countries, with their heavy levels of high speed traffic, dominated by the private motor car.

This report accepts that the principles are universal, but putting them into practice has to recognise some important differences. The conditions found in the less-industrialised countries vary enormously, but some or all of the following have been taken into account in the advice which follows:

1. Self-evidently neither the public authorities nor the vast majority of private citizens in developing countries have the means to spend much on lighting - which is probably seen as something of a luxury - an optional extra in the basic means of transport. This is made worse by the fact that much of the technology, although relatively simple, is imported and uses foreign exchange.
2. Similarly, skilled technicians and the resources to undertake all-important maintenance are at a premium.
3. The level of development in many developing countries is unevenly distributed, with the rural areas and villages having few of the amenities of the cities. In particular, mains electricity is a rare luxury - for domestic or public use.
4. Major parts of the road network, including the intercity links, are relatively lightly trafficked, especially in Africa. The rural networks have a high proportion of gravel (or even hardened earth) roads. Although many of these are properly engineered (in terms of structural strength, and vertical and horizontal curvature) the need for them to be maintained by grading rules out the use of surface markings.
5. To reduce capital costs in mountainous regions lower geometrical design standards are often used, resulting in sharp bends and steep gradients, and frequently poor sight-lines.
6. Many roadside features, such as large drains and culverts (capable of handling monsoon volumes of water) and bridge parapets have been installed close to the running surfaces of roads. This makes them especially unforgiving to driver error. The submerged or "Irish" bridge can be particularly hard to discern at night.
7. Poor maintenance of both urban and rural roads means that bad surfaces and potholes, together with poorly signed roadworks, are a common hazard.

8. Many developing countries lie in the tropics, where all evening social activity takes place during the hours of darkness. The warm temperatures encourage people to "live out-doors", and the roadways in townships and villages alike become social meeting places. The distinction between shops and business premises and the public highway is frequently blurred.
9. A wide diversity of vehicles uses the roads, many slow-moving compared to the motor car. Animal drawn carts, animals themselves, handcarts, bicycles, motorcycles etc. all compete for roadspace. Large numbers of pedestrians use the roadways - outside the central urban areas there are few sidewalks.
10. Because of high daytime temperatures many intercity bus services, and much long distance freight, operate through the night.
11. In developed countries there is a relatively clear distinction in the road hierarchy between through traffic routes (dominated and designed for vehicle flow) and pedestrian/residential areas. These distinctions are more blurred in developing countries, and there is a greater range of road types. The emphasis in this report is not on the centres of the major cities, where the traditional public lighting standards of the developed world can apply, but on the less-motorised regions of those countries: i.e. the sub-urban areas and rural areas, including village streets.

Because the "language" of lighting is somewhat specialised, the report starts with a short explanation of the terms and quantities used, and the basic mechanisms of vehicle and roadway lighting. It then deals, in order, with markings and signs (especially reflectorisation), vehicle lighting and fixed roadway lighting.

A consistent theme throughout the report is that it is better to make modest improvements rather than none at all. In other words, it is better to do something than nothing. Inaction should not be excused simply because the improvements that can be afforded fall short of the standards and ideals set by the highly motorised and more affluent countries.

2. LIGHTING BASICS

2.1 Fundamentals

All objects are seen by contrast, either dark against a light background (e.g. words on a page) or light against dark (a candleflame in the dark). Our ability to see them depends on this contrast, and we need more of it at lower lighting levels and when we need to see small detail. Unless the objects are self-luminous their contrast with the background comes from the amount of light directed at them which is returned to the eye of the road user, be they driver or pedestrian.

Vehicle headlights are most effective at making vertical features, on or off the road, appear brighter than the background. Fixed roadway lighting, on the other hand, works largely by making the road surface brighter than objects upon it, which are often seen as silhouettes with little internal detail. In both systems, light coming directly from the light source into the eye (glare) has to be kept to a minimum as it reduces the sensation of contrast. As will be seen later, this is a particularly intractable problem for vehicle headlighting.

2.2 Building blocks of lighting and definitions

2.2.1 Lamps

The lamp is the basic source of radiation. In transport lighting we are dealing almost exclusively with electric lamps, which convert electrical energy into electromagnetic radiation to which eyes are sensitive (light, in common language). There are three basic ways of doing this:

1. Passing current through a wire or filament to a high temperature, in a sealed bulb, the incandescent lamp. It is the oldest lamp type, comes in a wide variety of power ratings, is relatively rugged and cheap, and needs no special circuitry. It has, however, a low efficacy (see next section). Until recently it was the only lamp used in vehicle lighting.
2. Passing current through a gas or mixture of gases in a sealed tube, generically called discharge lamps. The light emitted depends on the gases and their pressure. With greater efficacy and with longer lives than incandescent lamps, they are used extensively in fixed roadway lighting. They are, however, more expensive and require special circuitry for starting and control. A miniaturised form of discharge lamp (HID-high intensity discharge) is starting to appear in vehicle headlights.
3. Passing a current through a semiconductor - the light emitting diode or LED. This has many of the desirable properties of the small incandescent lamp, but has higher efficacy, longer life, and is more rugged. LEDs are set to become the norm for all vehicle lighting with the exception of the headlights themselves, where (for the present) they cannot provide the necessary high powers from a small area/volume. However, this situation is also changing rapidly.

For all the lamps, it is their engineering properties which are of most interest, their efficiency in turning electricity into light, how that light can be directed where it is wanted, and their unit cost and average lifetime.

2.2.2 Power of light - the lumen

The radiation, or "luminous flux", which comes from a lamp is measured in lumens (lm). This quantity allows for the fact that the sensation of "light" experienced by the human eye/brain system depends on the wavelength of the radiation entering the eye. The same amount of energy at the opposite ends of the spectrum - red and blue - produces less sensation than in the middle (yellow/green). At the peak of sensitivity one watt of radiated electromagnetic power is equivalent to 683 lumens.

2.2.3 Efficacy

This is defined as the number of lumens produced by a lamp for each watt of electrical power it consumes. The unit is lumens per watt. From the comments in the previous paragraph it can be appreciated that efficacy is closely related to the wavelengths radiated by the lamp. A low pressure sodium lamp emits nearly all its radiation near the yellow "peak" and has a high efficacy of 200 lumens/watt, whereas a tungsten lamp emits most of its radiation in the infrared part of the spectrum to which the eye is "blind", and has a low efficacy of around 14 lumens/watt. The efficacy of LEDs is constantly improving: "white" LED sources are becoming available with efficacies approaching 100 lumens/watt.

2.2.4 Intensity - the candela

A lamp emits light in all directions. The flux emitted in a given direction within a very small solid angle "surrounding" the direction, divided by the solid angle, is the intensity in that direction. The unit of measurement, lumens per steradian, is called the candela (cd).

2.2.5 Luminaires and lanterns

Basic lamps are rarely used by themselves. The flux is directed where it is wanted by a combination of mirrors (reflection) and prisms/lenses (refraction). These are usually positioned in a protective housing together with some of the electrical fittings, and the whole unit is called a luminaire. In some countries a luminaire designed specifically for roadway lighting is called a lantern.

Light-emitting diodes usually have their flux directed by built-in lenses.

In all cases it is the intensity distribution and the overall efficiency of the luminaire, rather than the basic lamp it contains, which is of interest to the lighting engineer. He/she is also concerned about the ability of the luminaire to sustain its light output over long periods, despite degradation of the lamp or the optical components (including any protective transparent cover). This is dealt with in more detail under maintenance.

2.2.6 Illuminance

The flux from a luminaire travels in various directions through space until it strikes a surface. The amount of light falling per unit area of the surface is called the illuminance, and is measured in lumens per square metre or lux (lx). If the luminaire is at reasonable distance from the surface it can be regarded as a point source, and the illuminance (lx) on a surface perpendicular to the intensity direction is simply the intensity I (cd) divided by the square of the distance D (m). This is sufficiently accurate to calculate the illuminance of vertical objects lit by headlamps. In the case of the road surface under roadway lighting there is usually an angle, say G, between the plane of the road and the intensity direction. In this case the illuminance in lux is given by

$$\frac{I \cos G}{D^2}$$

or

$$\frac{I \cos^3 G}{H^2}$$

where H is the mounting height of the lantern.

2.2.7 Luminance

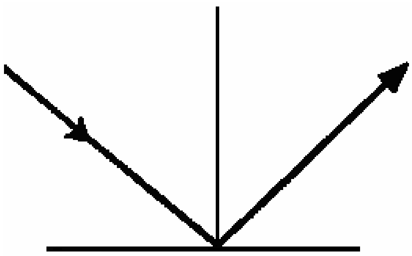
Finally, for an object to be seen, some of the light striking it has to be scattered in the direction of the driver's eyes. The measured intensity of this reflected light per unit area of illuminated surface is called the luminance of the surface, and is measured in candelas per square metre. It is the differences in luminance between various objects and their backgrounds which basically determine how visible they are. The concept of luminance is used also to describe the characteristics of extended light sources, such as internally illuminated road signs.

The relationship between the illuminance of a surface and its consequent luminance is quite complicated, as it depends on the direction from which the incident light strikes the surface, the direction from which it is viewed, and the inherent qualities of the surface itself - its reflection characteristics.

2.2.8 *Reflection characteristics*

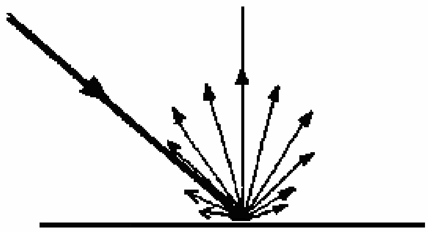
There are basically three types of reflection (see figure below). In specular reflection the light is not scattered but leaves the surface in one direction only, directly opposite to its direction of arrival, as in a mirror. A very wet road surface behaves in this way. In contrast, a perfectly diffuse reflector scatters light in all directions, in such a way that the luminance is the same for all angles of viewing (matt paper approximates to a perfect diffuser: white paper scatters far more than black, but the distribution of the scattered light is the same). In retroreflection the incident light is returned back in the direction of the source, with a very small spread in the light around this particular direction. Although one of the earliest retroreflective road markings was inspired by nature - the cat's eye - practical retroreflectors are manmade, and produced as either discrete items or in the form of sheets and panels. (See Chapter 3).

Most surfaces display a combination of specular and diffuse behaviour, with the specular becoming increasingly noticeable for large angles of incidence and observation (measured from the vertical), which is particularly the case for road surfaces. The reflection factors for typical road surfaces have been measured and tabulated.



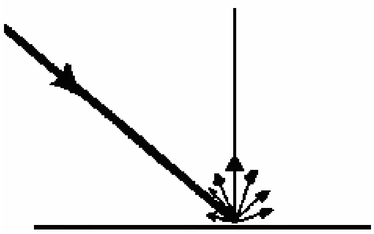
Specular reflection

Light "bounces" off the surface.



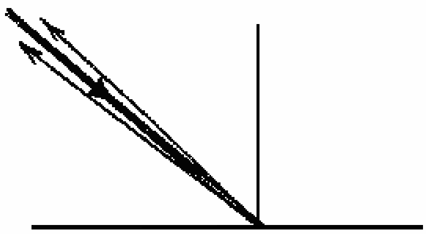
Diffuse reflection

Light scatters in all directions



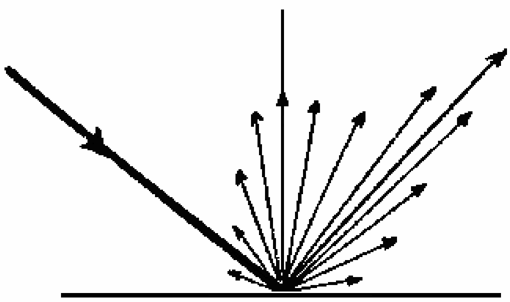
Diffuse reflection

at a "dark" surface - much light absorbed.



Retroreflection

Light returns in the incident direction



"Real" reflection

A combination of specular and diffuse, plus absorption

In the following chapters it will be shown how these fundamental facts and concepts about light sources and their properties, and the basics of "light engineering", can be applied to improve visibility during night-time driving. The three main areas to be covered are (i) signs and markings, where reflectorisation plays an important role, (ii) vehicle lighting, and (iii) roadway (fixed) lighting. They are presented in this order as it represents increasing cost and complexity.

3. MARKINGS, SIGNS AND REFLECTORISATION

Markings and signs are a basic and essential part of the road safety toolkit.

Road markings show the course of the road ahead, warning of bends, changes of width, intersections and roadside obstacles. On single carriageways they help separate opposing traffic streams, and at intersections they guide and help control safe behaviour. Words and symbols on the road surface reinforce the messages carried by signs. Although national standards vary, it is a common convention that continuous lines on the road surface should not be crossed, and broken ones can be.

At night-time the importance of their role increases, particularly in the basic task of helping the driver "read" the road situation ahead. On unlit roads markings and signs become the dominant part of the road scene, extending the range of the visibility provided by vehicle lighting. It is generally accepted that between 3 and 5 seconds of "preview time" is needed to follow the run of the road. The longer of these times corresponds to seeing suitable markings approximately 80 metres ahead at 60 km/h and 140 metres ahead at 100 km/h.

Road users also need additional "marking" at night, especially those without permanent lighting - pedestrians, animals, bicycles, agricultural carts, etc. Even motorised vehicles equipped with lighting need to be made more conspicuous, particularly from the rear, by passive markings.

This report concentrates on ways of making markings and signs more visible at night.

A key element in this is the use of retroreflective materials (more commonly, if less accurately, referred to simply as "reflectorised" materials). Because of their importance they are described in more detail in a later section.

3.1 Marking the road

3.1.1 Materials

The simplest and cheapest way of marking the roadway and highlighting key features is to use light-coloured paint (simply because most surfaced roads are dark or even black). Solvent paints are known as single component systems, consisting of a solvent and a pigment-carrying resin. The former, a hydrocarbon such as toluene or heptane, dissolves the resin and then evaporates into the atmosphere after application. Glass beads can be scattered onto the newly applied surface to give a degree of reflectorisation (see later). Because of concerns over pollution these volatile organic compounds are being replaced by water and a compatible pigment resin (based on acrylics or acrylates). Although taking longer to dry they are believed to be as durable as their organic forebears.

Thermoplastic materials give longer life than paint. These are solid materials provided in blocks or granules which are heated to around 180°C to liquefy them. They are applied extruded in thicknesses between 1,5 mm and 3,0 mm or sprayed in a film typically 0,75 mm thick. A degree of reflectorisation is achieved by either mixing beads into the material or scattering on the newly laid surface, as for paint. They typically dry in less than 10 minutes. Some skill is needed in their use, but preformed thermoplastic tapes are also available with a pressure sensitive backing that allows them to be stuck directly onto the surface.

Thinner, yet durable, markings which do not involve a solvent are available in what are known as two component systems. Epoxies consist of a resin and hardener, which have to be mixed exactly. Their hardening is irreversible. Polyureas are similar but are applied hot (around 65°C) and typically harden in less than two minutes. Other members of the two-component family are the Methyl Methacrylates, which are applied at normal temperatures and take longer to cure. However, these two-component systems require special equipment for mixing and application, and this can be expensive.

The following table summarises the pros and cons of the different materials.

Material	Ease of use	Thickness (mm)	Durability (years)	Initial cost	Relative annual cost
Solvent paint	1	0,2	1 or less	1	1
Water paint	1	0,2	1 or less	1	1
Extruded thermoplastic	2	1,5 to 3,0	3 to 4	5	1,25 to1,7
Sprayed thermoplastic	2	0,75	1 to 2	3	1,5 to 3,0
Preformed tape	2	1,5 to 2,3	4 to 8	10	1,25 to 2,5
Epoxy	3	0,4 to 0,6	3 to 4	3	0,8 to 1,0
Polyurea	3	0,4 to 0,6	3 to 5	6	1,2 to 2,0
Methyl methacrylate	3	1,0 to 3,0	3 to 5	6 to 10	1,2 to 3,3

Note. Ease of use: 1=easiest, 2=more difficult, 3=most difficult.
Initial cost: On a scale of 10, with 1 the cheapest, 10 the most expensive.

Because the illuminance of a surface falls off dramatically as the angle of incidence approaches 90 degrees, markings which rely on scattered light from headlights are more effective at night if they have vertical faces. With thicker thermoplastic markings it is possible to imprint a ridged texture which goes some way to providing this.

On unpaved roads in particular, the edges can be highlighted by markers. These can range from sophisticated reflective blocks mounted at a height of about 0,5 m on light-weight fabricated posts (so as not to endanger vehicles running off the road), to simple white painted rocks embedded near the road edge at regular intervals. Marking of larger obstacles near the roadside serves as both a warning of the danger they might pose and an indication of the run of the road, again, materials ranging from white paint to reflectorised blocks can be used.

In this picture, the white vertical posts have a reflective band about two-thirds of the way up: despite their solid appearance they are made of plastic. The paint on the trees is a simple matt paint with no reflectorisation.

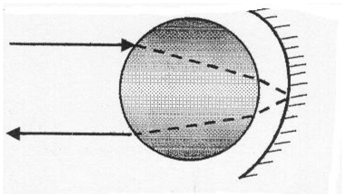
3.2 Retroreflection

As explained in the previous chapter, a retroreflecting object returns a significant amount of the light falling on it back in the direction from which it came. Its effectiveness in night-time safety relies on the fact that a driver's eyes are very close (spatially) to his vehicle's headlights, particularly when the retroreflecting object is some distance away. A retroreflectorised object is considerably less bright for others viewing from wider angles.

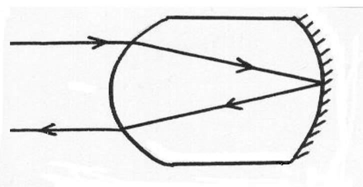
3.2.1 Retroreflective materials

Two types of optical elements are used to retroreflect light.

(i) Spherical (or near spherical) glass or plastic elements. These can be large (studs) or small (beads). Between 3 mm and 10 mm in diameter they can be engineered with a larger radius at the rear to coincide with the focal plane; reflectorising this gives a high degree of retroreflection.



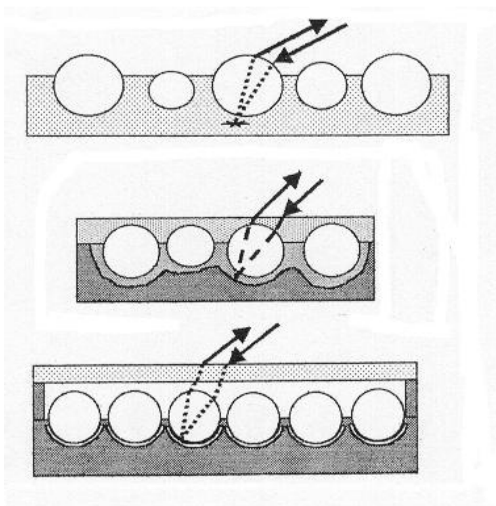
Bead optics



Stud optics

The original cats-eyes, shown on the right, consisted of four reflectorised glass studs, two facing in each direction, mounted in a tough rubber housing which deformed under traffic and simultaneously wiped the glass surfaces clean.

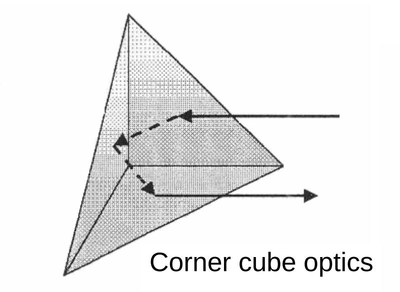
Small beads (microspheres, ballotini) although not optically engineered also produce a useful degree of retroreflection. In the simplest arrangement the beads are embedded in a weather resistant binder (paint, thermoplastic or some other material) which also contains a pigment providing the reflector layer and the marking colour. The upper part of the spheres can remain exposed to the air, or be covered with a transparent plastic material which acts as both a protection and as part of the optical system. For road markings, a simple version of the first arrangement is achieved by simply mixing a quantity of beads into the various line marking materials.

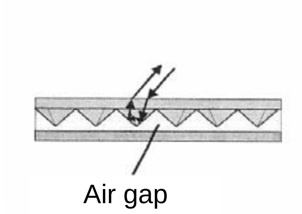


Retroreflective microspheres.

In a third system (shown at the bottom), the glass spheres are in an air-filled capsule and their lower faces coated with a reflecting material.

(ii) Corner cube or prismatic structures, in glass or plastic. These rely on an optical phenomenon called "total internal reflection"; light travelling in a material such as plastic or glass which arrives at the surface with the air is completely reflected if it strikes the interface above a certain angle. The corner of a cube provides a succession of such interfaces.



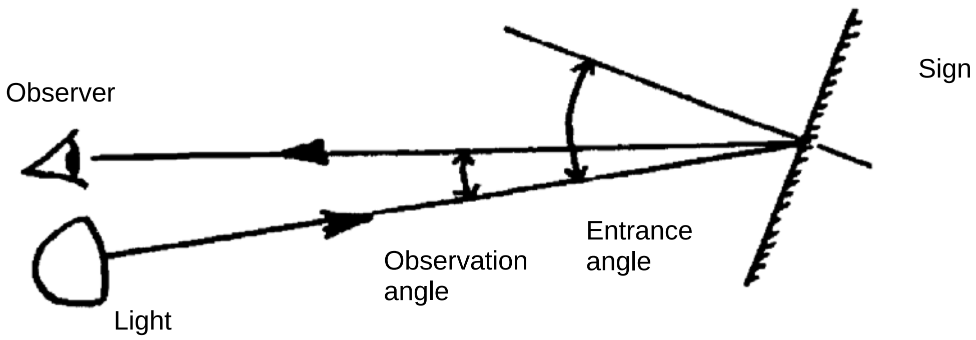


Both these structures, spheres and prisms, can be miniaturised and used in a variety of forms, either as small discrete devices or as rigid and flexible sheets. A wide range of commercial products has been developed, embracing small discrete units for mounting on vehicles and for setting into the road surface, and rigid and flexible sheets for signs and other large surfaces.

It should be noted that raised discrete markers are particularly effective on wet roads, when simple horizontal markings lose much of their performance.

3.2.2 Performance

The photometric performance of signs and surface markings is expressed in terms of the luminance (cd/m^2) produced by the illuminance (lumens/m^2, or lux). This ratio, called the "coefficient of retroreflection" (*R*) depends on the angle of the incident light (the entrance angle) and - most critically - on the angle between this direction and the observer (observation angle).



Specifications for reflective sheeting give minimum *R* values for specific observation and entrance angles. Small observation angles are relevant to long range signs and markers where the emphasis is on conspicuity: larger angles are associated with closer viewing and legibility. For signs which are exclusively for short-range viewing the entrance angle can be reduced by angling the sign slightly towards the road.

Sheet materials for vertical signs and markers are produced commercially in two qualities. The minimum recommended values of *R*, in cd/m^2/lux, are given below for two geometries (i) an observation angle of 0,3° and an entrance angle of 5°, and (ii) an observation angle of 2° and an entrance angle of 30°. The four most common colours are quoted.

	Observation angle	**Entrance angle**	cd/m^2/lux			
			Red	**Orange**	**Yellow**	**White**
Class I	0,3°	5°	10	25	35	50
	2°	30°	0,4	0,8	1,5	2,5
Class II	0,3°	5°	25	65	122	180
	2°	30°	0,4	0,8	1,5	2,5

The photometric performance of small individual devices - cats-eyes, studs, blocks, etc. - is measured in terms of the total intensity in relation to the incident illuminance. This quantity, called the coefficient of luminous intensity, is usually quoted in millicandelas per lux. Minimum desirable values are given in the following table. (The entrance angles are the horizontal angles - it is assumed the device is fixed horizontally on the road surface.)

Observation angle	Entrance angle	mcd/m^2/lux		
		Glass	**Plastic**	**Hardened plastic**
0,3°	±5°	20	220	150
1°	±10°	10	25	10
2°	±15°	2,0	2,5	1,5

These figures are for white reflectors: colour factors are red and green 0,2, orange 0,5, yellow 0,6.

3.2.3 Application

The positions and types of signs and markings will normally be specified in any particular country for what is, in effect, daylight driving. Wherever possible, they should all have some measure of retro-reflectorisation for night-time safety.

White road studs or markers are used to show traffic lanes or the centreline on single lane roads. Lane markings or edges of roads which must not be crossed are marked red or orange - conventionally red on the nearside, orange on the offside. Green shows a lane-line which can be crossed, as at the exit of a motorway.

As a rough guide, markers should be placed every 10 metres or so on single two-lane roads, and closer on bends.

It is a useful discipline for the highway engineer to travel unlit roads and look critically at the scene ahead, watching out for unexpected and misleading impressions. Frequently they can be corrected and the true picture restored by highlighting a few key features. For example, in many developing countries there is little provision for pedestrians on bridges, and the solid abutments appear at the very edge of the road. These should be highlighted, with white paint as a minimum. Lengths of straight road which suddenly change direction need both warning signs and chevron markers.

If resources are very limited, markings should be concentrated on lengths of road where there are bends or crests and hollows (changes in horizontal or vertical curvature) and any unexpected features, such as a changes of width.

Mountainous roads require special attention, and both centre markings and edge markings should be used where possible, especially on and near hairpin bends. Chevron and other reflectorised markers can be mounted vertically on fences or barriers on the outside of the bends. These barriers need not necessarily be the expensive steel structures of the industrialised countries; in Nepal, for example, gabions are used to restrain "runaway" vehicles, and can carry reflectorised panels.

An interesting development whose use might be justified for particularly dangerous sites is the internally illuminated road stud (or post marker). This uses red light emitting diodes, and the bodywork incorporates a miniature photovoltaic cell and storage battery. Similar technology can produce an internally illuminated sign in areas far from a supply of mains electricity. Internally illuminated signs can, of course, be used in central urban areas, but these introduce their own problems of maintenance and cost. For wider application reflectorisation almost certainly provides the best overall solution.

3.2.4 Marking the road user

As mentioned earlier, road users also need additional "marking" at night. Those without permanent lighting, pedestrians, animals, bicycles, agricultural carts, etc. are particularly vulnerable. Even motorised vehicles equipped with lighting need to be made more conspicuous, particularly from the rear, by "passive" markings.

Corner-cube reflectors offer the highest efficiencies for mounting on vehicles. Commercial vehicles should also be encouraged to use reflectorised strips and sheets to show the outlines of their vehicles. This should not be difficult in Asia where trucks are traditionally highly decorated, although departure from the strict geometrical lines of Western traffic culture may be necessary.

Less formal road users should mimic this behaviour, particularly using red reflectors to the rear. Cyclists, notoriously careless the world over about their visibility, should be protected by embodying reflectorised elements in the bicycle itself. Pedal blocks are especially effective: wheel mounted reflectors less so except when a cyclist is turning across the traffic. All reflectors should be mounted as low as practicable to take advantage of low-beam headlights (see also Chapter 4).

Road safety publicity should encourage greater use of bands and strips of reflectorised clothing, a wide variety of items is available and can usefully be the focus of commercially sponsored campaigns. The sponsor's name can easily be incorporated in, for example, dangle tags, pinned to clothing or worn as bracelets. Children in particular need warning (perhaps showing?) that the power of these gadgets is limited - they possess no magic properties.

This theme could well be included in general road safety education for children and adults alike. Drivers in general do not appreciate how little of the road and its surroundings can be seen at night, nor how near the limits of safe driver performance they are. Pedestrians also overestimate the effectiveness of vehicle (and street lighting) in making them visible.

3.2.5 Emergencies

It is common practice in developing countries to warn of broken-down vehicles by putting rocks or tree branches in the road. This is often barely adequate in daylight, and usually inadequate at night. If it is not already a legal requirement, the carrying of emergency triangles should be introduced, perhaps starting with commercial/goods vehicles.

Even a simple white-painted triangular board (left), propped against a stone, is more visible at night than the traditional debris. The more ingenious drivers could improve on this by emphasising the triangle with red paint and fastening three red bicycle reflectors at each apex (centre). A typical commercially-available triangle which folds up and has a built in support is shown for comparison (right).

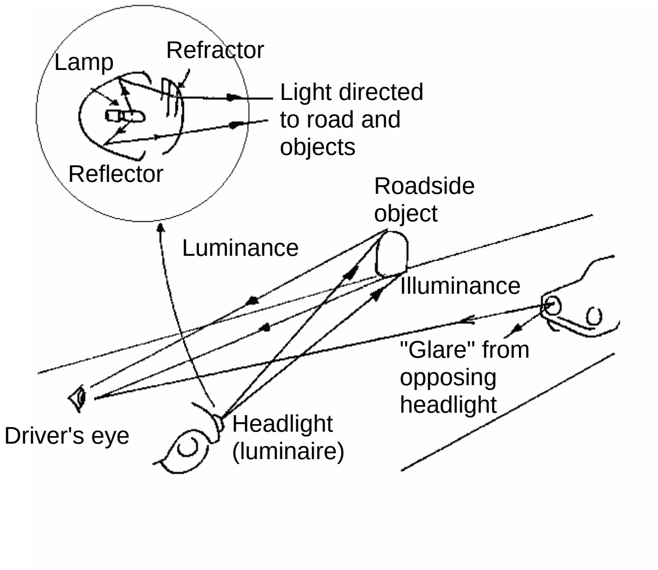
4. VEHICLE LIGHTING

Vehicle lighting falls into two broad categories: lighting for seeing and lighting for being seen. The latter includes signalling and braking lights, but as these are not exclusively for night-time driving they will be given less emphasis. Our definition of "vehicle" will be extended to include any moving object, animate or inanimate, to be found on the road at night.

Most, if not all, of the vehicle lights in developing countries originate in the industrialised vehicle-producing countries and are subject to the relevant type approval standards. These are set by the National Highway Traffic Safety Administration (in Federal Motor Vehicle Safety Standard 108) for the USA and by the United Nations Economic Commission for Europe for the European nations (these standards are also used by Japan).

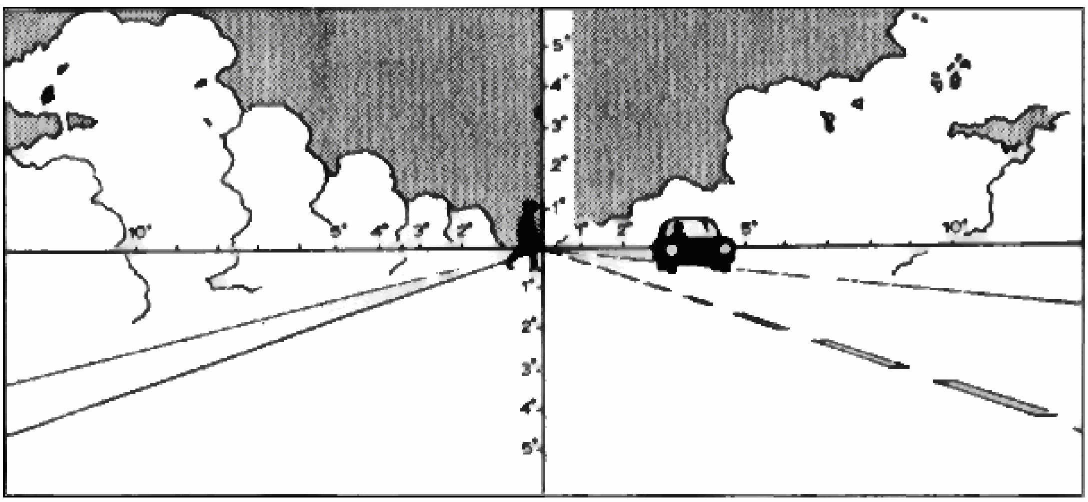
4.1 Headlamps - lighting for seeing

The basic elements of lighting the road by headlamps are shown in the following figure. This demonstrates why headlighting is a serious challenge to the skills of the lighting engineer.



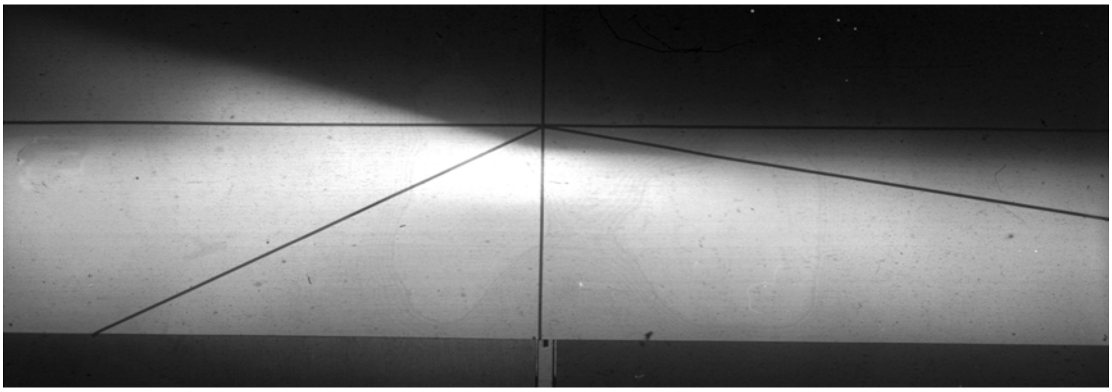
Basics of vehicle headlighting.

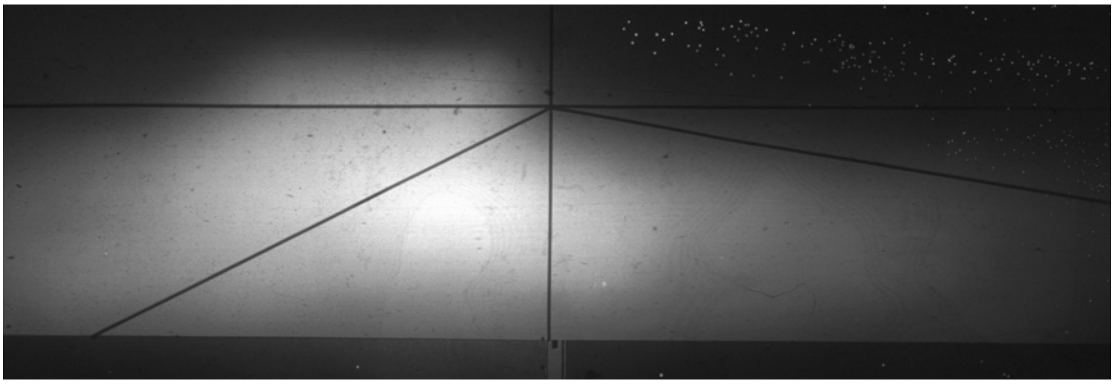
The basic problem is to direct sufficient light onto the road and roadside without simultaneously causing glare to an oncoming driver. Even on a flat level road the critical directions are dangerously close. This is clear from the view of the road from a typical car headlamp position:



The pedestrian figure is 60 metres away, a distance within which a car with good brakes could stop if travelling at 80 km/h (50 mph). There is only about 1 degree of vertical separation between the pedestrian's feet and the oncoming driver's eyes, and around 4 degrees of horizontal separation.

Two dipped (or passing) beam patterns have evolved, the European and the American. Both are designed to minimise the intensity in the sensitive "glare" direction, while maintaining high intensities below the horizontal and to the nearside of the road.





The diagrams show the general light pattern projected towards the road by the two types of headlamp (as seen from the headlamps' perspective) for left-hand drive traffic. The European beam (upper picture) has a relatively well defined horizontal cut-off running up at 15 degrees to the horizontal on the nearside and a broad spread horizontally. The American beam (lower picture) has greater intensities to the nearside and a softer cut-off. The standards set for the intensity distributions are meant to guarantee maxima in certain directions and minima in the "glare" direction. Inevitably this is a compromise: no current system in widespread use can allow for bending and undulating roads, and the variety of positions for objects and features of importance. A moving vehicle, particularly on rough roads, is hardly the ideal mounting point for what is essentially a fairly precise optical projector.

High beam intensities are usually adequate for driving on open roads at normal speeds in the absence of opposing traffic. The specifications for the "straight ahead" direction (the HV position) are as follows:

Specification (at 12,8 V)	**American**	**European**
HV- maximum	75000 cd	140000 cd
HV - minimum	20 - 40000 cd	30000 cd

The seemingly large difference in central intensity is not so dramatic when translated into seeing/visibility distances. Both the illuminance at a distant object and its angular "size" decrease as the square of the distance: field experiments suggest that for dark obstacles a doubling of the intensity from 75000 cd yields only a 10% increase in visibility distance. (This is arguably the worst case - lighter and reflectorised obstacles would show greater improvements).

Supplementary high-beam lighting can be added e.g. for long-distance night-time goods vehicles, and to increase the lateral spread of light in featureless/desert terrain. If any supplementary lights have significant intensities above the horizontal, i.e. if they are similar to main beams, then they must be wired to go out automatically when headlamps are dipped.

Because of the greater amount of roadside activity after dark in many developing countries, it has been proposed that the normal dipped beam should be augmented - or even replaced - by a wider "town" beam, specifically designed for the purpose. Its intensity distribution would be similar to a fog-lamp with a sharp upper horizontal cut-off.

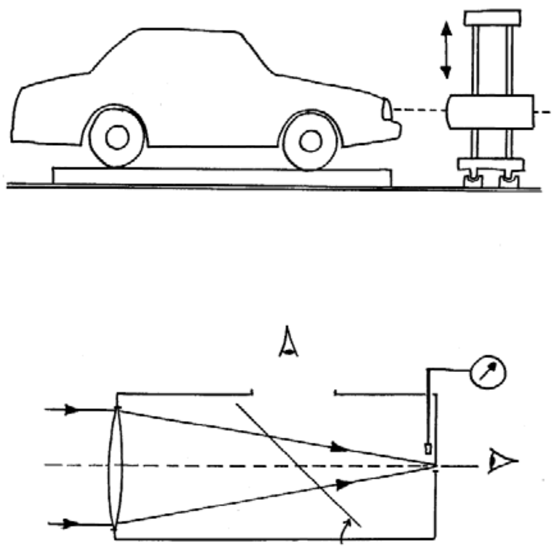
Headlamp technology continues to evolve. Higher intensities (and/or wider beam patterns) are possible with headlamp units incorporating miniature high-intensity discharge lamps (typically 3000 lumens at 35 watts), instead of the conventional tungsten or tungsten-halogen lamps (typically 1500 lumens at 55 watts). These require special circuitry and careful aiming, maintained in service, but the considerably longer lifetimes make them potentially attractive for developing countries, once their initial high cost can be brought down. Sustained long-life output of the main-beam is particularly valuable for the less motorised and/or lightly populated countries, where the dipped beam is used proportionately less.

4.2 Aiming of headlamps

Given the inherent intensity distributions of the headlights fitted to their vehicles, vehicle users and developing country administrations have to concentrate on establishing and sustaining their aim and general condition.

Checking of headlamp aim should be a part of any national vehicle inspection system, but individuals and companies should be encouraged to make more frequent checks and corrections. Aiming can be either mechanical - where reference markings on the headlamp unit are adjusted to coincide with markings on the vehicle body - or visual, where the headlamp beam itself is examined with respect to the "plane" of the vehicle. This is preferable, as it relates more closely to real road conditions.

The vehicle is loaded to its "normal" conditions and a collimating system is placed in front of each lamp in turn. The cut-off image is examined for position and corrections made to the headlamp unit. Intensities can also be measured with the more sophisticated devices (usually a quick check on maxima and minima at a couple of test points with the engine running at normal speed).

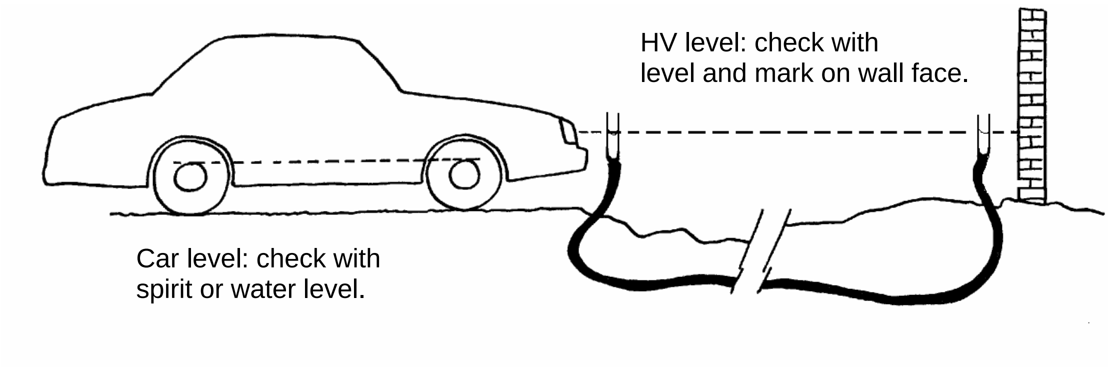


Basic optical headlamp aiming equipment

Individuals should also be encouraged to check the aim of their own lights regularly. At its simplest this could be a critical look at the dipped beam pattern when driving on a flat level road - for European beams the cut-off should be visible on the road about 45 metres away. More thoroughly, the vehicle should be parked on a flat and level off-road site about 10 metres in front of a wall (preferably white) or temporary vertical screen. The vertical and horizontal axes through the centre of the headlamp can be marked on the screen by:

(i) either sighting along a line which is parallel to the vehicle axis using, for example, the centres of the two wheels;

(ii) or, if the ground on which the vehicle rests is reasonably level and horizontal the position of the horizontal plane can be marked on the wall using a water-tube spirit level.



Each lamp is checked in turn, with the other masked, remembering that the vertical aim is the more critical. At 10 metres, an angular shift of 1 degree corresponds to a distance of 17,5 cm on the screen. European lamps are aimed using the cut-off of the dipped beam for reference. If the mechanical marks of an American lamp system are unidentifiable or unusable the beam should be aimed using the high-beam, aiming the "hot-spot" centrally on the HV axis.

For commercial fleets a site within the garage area could be set aside and a suitable wall marked with aiming reference marks for different vehicle types when they have just been aimed with more sophisticated test centre equipment. Approximate, but rapid in-service checks can then be made.

A list of points to help the individual user get the best out of his/her headlamps, and which could also be used in road safety campaigns or highway codes, is given in Appendix 1.

4.3 Marker lights - lighting for being seen

The presence of headlamps makes vehicles highly visible from the front, although most modern headlamp units also incorporate a lower-wattage lamp for use when the vehicle is stationary. As with headlamp units, the specifications and developments of rear-light units have evolved to meet the needs of the high density traffic of the industrialised countries. The multi-compartmental units of today's vehicles usually incorporate running (presence/tail) lamps, brake lights, now reinforced with a third lamp mounted higher on the vehicle, turning indicator lights and reversing (back-up) lights. The specifications ensure that the various functions of these many lamps are met and do not interfere with each other. Even so, there is probably room for improvement; nearly 30% of all crashes in the USA, for example, are rear end, although obviously not all taking place in the dark.

Marker lights convey several items of information simultaneously:

the presence of a vehicle/road user;

its width/overall size (and hence a clue as to its type);

its distance;

its relative speed - is it getting closer to or receding from the observer?

Other lights in the rear unit can show whether the vehicle/road user:

intends to turn;

is braking (in some systems how severely);

is reversing or intends to do so;

is stopped because of an emergency (all four turning indicator lights flashing).

The specifications for this second group of lights are geared towards daytime viewing and are more than adequate for night-time conditions.

The basic requirement for night-time marking is two white lights at the front and two red lights at the rear. For motorised vehicles the headlights fulfil the frontal requirement as long as the vehicle is moving. Non-motorised vehicles, especially two-wheelers, do not usually have the physical width to carry two distinct lamps.

Unfortunately, a single light source carried/held by a road user can signal only presence; a solitary disembodied point of light in an otherwise dark view simply warns that something is there. If it obeys the internationally accepted convention of white to the front and red to the rear it can, by inference, suggest whether it is travelling in the same direction as the observer and probably on the same side of the road. However, even this basic and incomplete amount of information is worth having.

Doubling the number of lights to mark the extremities of the vehicle brings immediate benefits. Some estimate of the vehicle's distance can be made and, perhaps more importantly, its motion relative to the observer (the eye is remarkably good at detecting this when two reference points are available). Obviously this benefit is difficult to achieve with two-wheelers, although having two lamps mounted with a small separation - effectively increasing the visual area - can bring a small improvement.

If only one marker lamp is working - front or rear - and a spare lamp is not readily available the offside should be given priority (this should only be done as a temporary measure).

Commercial vehicles can usefully indicate their size by extra pairs of marker lights at the top of their bodywork and also along their sides.

Intensity specifications have gradually increased in the industrialised countries with increasing traffic and technical advances. In the early days of American motoring it was specified that a tail lamp had to be visible at just over 150 metres (500 feet); this could be achieved by a red light with a minimum intensity of 0,1 cd at the HV point, and a minimum of half of this within a 30 degree conical angle of the HV point. A maximum of 5 cd anywhere in the pattern was also specified. The minimum is now 2 cd and intensities are specified over a photometric grid covering 20 degrees to left and right and 10 degrees above and below the horizontal - the minimum at the extremities of this grid is 0,2 cd and the intensity above the horizontal must not be greater than 15 cd.

The current European regulations call for a 4 cd minimum at the HV point, double that in 1967, with a maximum of 12 cd - the specified photometric field is the same as the American. In addition, there is a requirement on the angular field in which all or part of the lamp surface shall be visible, a minimum of 0,05 cd has to be "visible" from 45 degrees either side of HV and 15 degrees above and below the horizontal.

The value of these figures is not so much in verifying that imported vehicles comply with accepted norms (for which the full specifications would be needed) but in suggesting the kind of intensity values that are needed for marker lighting on non-motorised vehicles.

4.3.1 Lights for non-motorised vehicles/road users

There is no serious power limitation on providing lighting for motorised vehicles, the power requirement is a small fraction of that usually available. But for non-motorised road users the absence of an adequate, and reliable, power source is the key problem.

Current bicycle lighting standards in the UK call for HV intensities of 400 cd to the front (white) and 4 cd to the rear (red).

These intensities can be achieved with power sources of a few watts, but the angular spread is obviously limited. Front lighting in particular can really do no more than act as marker lighting - the available light can only provide weak illumination of the road in the immediate foreground. This can be useful for negotiating poor and pot-holed roads at very slow speeds but has little bearing on safety; for that, it is more important that the (white) front-facing lamp gives a good warning of presence to motorised and faster-moving vehicles.

The power sources available to cyclists are batteries and small generators (dynamos).

The cheapest and most readily available battery in developing countries is the basic zinc-carbon primary cell, but despite its low cost it is the least cost-effective in terms of the energy delivered. Alkaline manganese cells are roughly twice as expensive, but are considerably more cost-effective. However, both types have to be discarded when exhausted - a possible threat to the environment. Rechargeable batteries (secondary cells) such as nickel-cadmium and nickel metal hydride are increasingly available and despite their initial high cost are the cheapest in the long run. The following table summarises the situation for size D batteries of each type, discharging at 0,5 amps (two cells in series with a 1,2 watt/2,5 volt tungsten lamp). The figures can only be approximate as technical improvements and prices are constantly changing.

Type of cell	**No. of cycles**	**Nominal capacity (Ah)**	**Useful energy (Wh)**	**Approx. life (hours)**	**Approx. relative cell cost**	**Relative cost per Wh**
Zinc carbon	1	5,5	2,2	3,7	1,0	106
Alkaline	1	16,0	14,0	23,3	2,0	33
Ni-Cd	100	4,0	400	667	8,5	5
	200	4,0	800	1330	8,5	2,5
	500	4,0	2000	3350	8,5	1,0

Small dynamos, driven by the bicycle wheels, are an attractive option for developing countries. Rated at about 3 watts - 4 watts at normal riding speeds they can still deliver half this power at 5 km/hour. An ideal combination is a dynamo linked to a secondary cell, the latter taking over at very low speeds or when stationary (bicycles are frequently used as load carriers and pushed at walking speeds).

The future is likely to see wider use of small solar panels linked to rechargeable batteries. Such systems are growing in use for static applications, and are particularly attractive when linked to lamps of higher efficiency, such as the light emitting diode.

4.3.2 The light-emitting diode

Low voltage tungsten filament lamps in the 1 watt - 2 watt range typically emit 10 lumens - 20 lumens, which if distributed uniformly yields intensities in the 1 cd - 2 cd range. If the red colour for a rear marker light is produced by a simple filter the intensity drops by an order of magnitude, making the effective efficiency around 1 lm/watt. Although 0,1 cd - 0,2 cd was typical even for motorised vehicle marker lights in the early days of motoring, it falls far short of the standards of today’s industrialised countries, demonstrating that reflectors and/or lenses are needed for practical lights.

However, light emitting diodes are much more efficient, currently between 50 lm/watt and 80 lm/watt. At this level even a small 100 milliwatt lamp can emit 3 cd over a wide angle, suggesting it makes an ideal light source for low-cost or even "home-made" rearlights for bicycles and other non-motorised vehicles. An added attraction is that the intensity distribution can be largely controlled by the way the solid state chip is encapsulated. The device is, in some senses, its own luminaire - doing away with the need for external lenses and/or reflectors.

With lifetimes of over 50 000 hours being claimed it is easy to appreciate their potential for almost all aspects of transport lighting. Lamps capable of 100 lm/watt have been demonstrated in the laboratory, and the industry has an ambitious target of 150 lm/watt for

2012. Front marker lights on cars are already in development, a 5 watt LED giving 150 lumens is now available, and the technologists have their sights on a 500 lumen package at 50 lumens/watt. The future looks - literally - bright.

The well-equipped bicycle.

Red rear light, the most important item.

If this cannot be provided a red reflector is the basic minimum.

The unit pictured incorporates both.

Reflectors in the pedals are very effective. They are seen from both front and rear, and their movement is eye-catching. Being near the ground they are in the most intense zone of the dipped headlight beam.

White front light. Because of its inherent low power it has limited value for illuminating the roadway itself.

If this cannot be provided then a white reflector should be fitted. As with the red rear light shown above, this unit has both.

Reflectors fastened to spokes have some value if the bicycle is turning or crossing the main traffic flow, but they are low priority items and should not be fitted in preference to the items above.

Simple dynamo powers both front and rear lamps

4.4 Temporary marking of non-motorised vehicles

Many non-motorised vehicles may have to be on trafficked roads in the dark only occasionally: agricultural carts, horse-drawn trailers, etc. These should be marked front and rear temporarily with portable lights, even the bicycle lamps mentioned above can be used if they are battery-powered. If these are not available, the most common domestic source of lighting for rural households - the kerosene lamp - could be pressed into service. These typically emit 50 lumens of yellow/white light, giving intensities of 4 cd without any additional optics, which is sufficient for marking. (It is unlikely that a red filter would be available for the rear, but it is better to show some backwards light rather than none at all). The more sophisticated kerosene pressure (or Tilley) lamp gives a light output an order of magnitude higher.

However, it must be remarked that both lamps are very inefficient, with the simple kerosene lamp achieving around 0,1 lumens per watt. There is a worldwide effort to see their replacement for domestic use by portable or handheld solar lamps. For example, a unit consisting of a small solar panel coupled to a Ni-Cd rechargeable battery can give around five hours of output from a 4-8 watt compact fluorescent tube for domestic use.

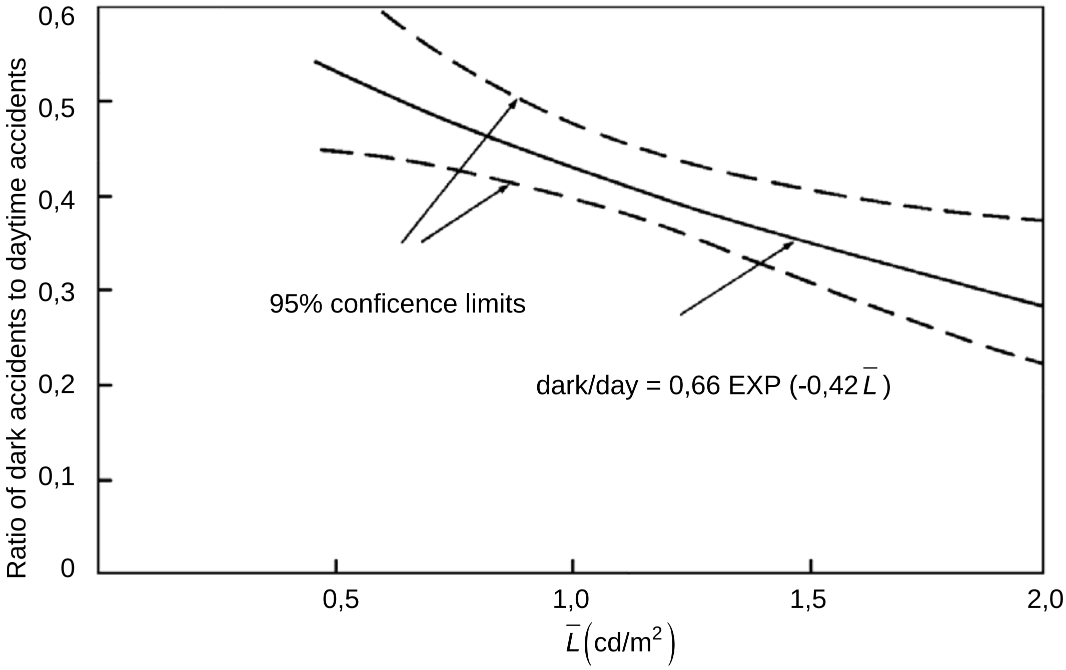
Finally, any road user at night, vehicle, pedestrian or animal, without access to a power supply or any form of light, should at least try to improve their visibility. Use of reflectorised materials takes priority here: (see Chapter 3: Markings, signs and reflectorisation). In their absence, white/light coloured panels of material should be worn or fastened (even temporarily) to the rears of vehicles and their loads. If possible, these should be placed on the lower part of the vehicle where an approaching motorised driver would expect to see marker lights and where the intensity of his dipped beams is highest.

When death or injury can be the penalties for not being seen, any improvement is better than nothing.

5. FIXED ROADWAY LIGHTING

The installation of fixed roadway lighting is the most effective way of improving night-time visibility. But it is also the most expensive, both in its initial installation and in its running costs. To realise its full potential it has to be well designed, correctly installed and consistently maintained. It can only be justified where there are relatively high traffic flows and accident rates, or where there are special needs or circumstances.

The experience in highly motorised countries is that lighting of even a modest standard can reduce night-time accidents on all-purpose main roads by about 30%.



Increasing the quality of the lighting can bring further benefits. The curve shown above is the ratio of night to day accidents, and comes from a comprehensive study in the UK on speed-limited all-purpose roads. It demonstrates that for road luminances in the range 0,5 cd/m^2 to 2,0 cd/m^2 further reductions of 35% can be achieved for an increase in average luminance of 1 cd/m^2. This shows that a top quality installation could halve the night-time accident rate if there were no previous lighting, or reduce it by a third by upgrading an existing low quality installation. It also offers encouragement to developing countries: even a very modest installation is better than none at all.

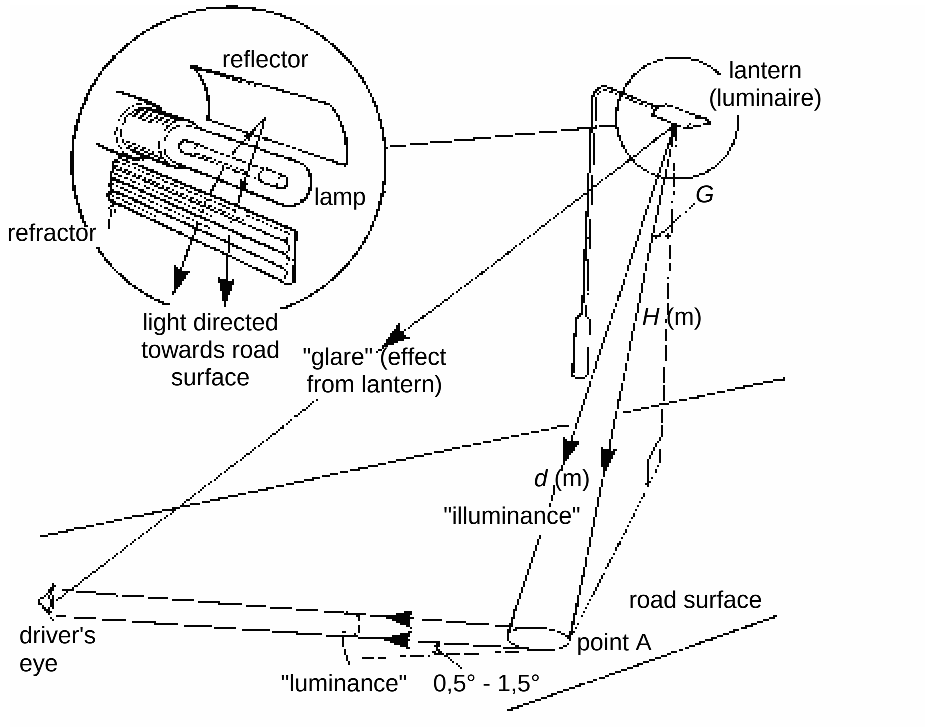
At the global level, countries typically lose between 1% and 2% of their gross national product in traffic accidents. If this applies at a more local level we could consider, for example, a city of 1 million people in a country with a GNP/capita of 1000 €. At the upper limit of 2% GNP this equates to a "local" loss of some 20 M€, of which 6 M€ would be from night-time accidents. Upgrading the lighting could save around 2 M€ - a measure of a reasonable overall budget for capital and running costs.

Unlike reflectorisation and vehicle lighting, fixed roadway lighting does more than just reduce night-time traffic accidents. It can also:

1. reduce the level of petty crime and personal robbery, and give citizens a better feeling of security;
2. encourage the night-time use of the road network, reducing day-time congestion;
3. preferentially help those road users with little or no "on-board" power generating ability - the non-motorised, two-wheelers, etc. - to see potholes and small obstacles;
4. on multi-purpose roads, enhance commercial and social activity during the hours of darkness, particularly after dusk; small installations in village centres, even operating for a few hours, can enhance community life;
5. make urban centres more attractive, especially for visitors and tourists.

5.1 Designing a lighting system

There are two principal tasks facing the highway lighting engineer when designing an installation. First there is the choice of overall quality, related to the function of the road/area to be lit. Second there is the selection and positioning of the lamps and luminaires, and the positioning of the latter above the roadway to give the desired level, spread and uniformity of luminance. At the same time the designer has to minimise the amount of glare from light entering the road user's eyes directly.



Basics of roadway lighting.

5.2 Lighting standards

The overall quality of an installation has several components:

1. Average luminance level. This is all-important, as it not only impinges on the safety benefits (see above) but also largely determines the power requirements and hence the running costs. In most simpler design processes, and for checking the performance of an installation, this translates into average illuminance level.
2. Overall uniformity of luminance, or illuminance, both across and along the roadway. Defined as the minimum divided by the average, and designated U_0.
3. Uniformity of luminance, or illuminance, along the axis of the road, usually an axis which coincides with a typical driver's eye position. Defined as the ratio of the minimum to the maximum, and designated U_1.
4. The lighting of the area adjacent to the carriageway to illuminate any footpath or surroundings. Considering two strips 5 metres wide (one in the road, the other alongside), the illuminance on the off-road strip should be at least 50% of the other.
5. Glare. As glare has the effect of reducing contrast, a luminaire's "glare performance", or optical control, can be expressed in terms of the increase in background luminance necessary to compensate (threshold increment, *TI*). The lower the figure the better. In highly motorised countries 10% is specified for motorways, with 15% and even 30% allowed for general traffic routes. These percentages are determined by the amount of light the luminaires project near the horizontal. This light also causes problems of sky-glow (see later).

6. Guidance. Whilst glare must be kept under control, a small amount of direct light from the luminaires gives a useful sense of the "run" of the road ahead, and can forewarn the approach of junctions or roundabouts.

5.3 Choosing the standards

Considering the vehicle types (and hence speeds and stopping distances) frequently found in the less industrialised countries, the following values for the components listed above are suggested. These should be regarded as for guidance only: it is generally better to relax the "quality" indicators of uniformity and threshold increment rather than have no lighting at all.

For areas where most of the "traffic" consists of pedestrians and non-motorised vehicles the figures are for illuminance; for recognised traffic routes the figures are for luminance, but roughly equivalent values of illuminance, for moderately dark road surfaces, are given in parenthesis.

Category	**Average level**	U_0	U_1	*TI*
Residential areas, pedestrians and many nmvs.*	1-2 lux	0,2	n/a	n/a
Largely residential, but some motorised vehicles	4-5 lux	0,2	n/a	n/a
Major access roads, distributors and minor main roads	0,5 cd/m^2 (~8 lux)	0,4	0,5	n/a
Important rural and urban traffic routes	1,0 cd/m^2 (~15 lux)	0,4	0,6	20%
High-speed roads, dual carriageways	1,5 cd/m^2 (~25 lux)	0,4	0,7	15%

Note: for the first two categories, the uniformity index is the ratio of the minimum to the average illuminance; for the remainder the index refers to luminances.

(*non-motorised vehicles)

5.4 Achieving these standards

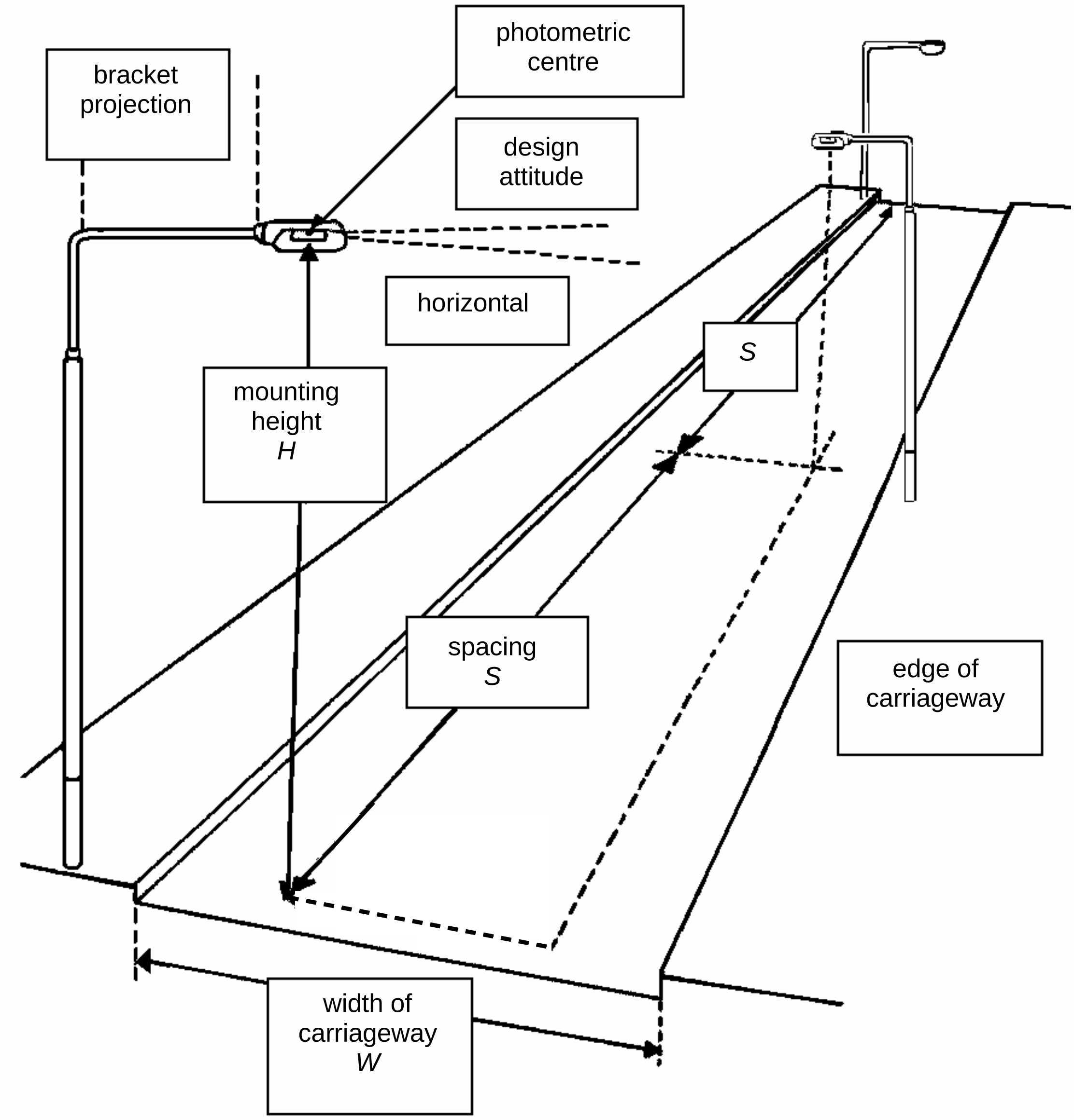
The basic geometry of road lighting and definition of terms commonly used is shown on the next page.

The lighting designer has the following parameters at his/her disposal:

1. Mounting height. The greater the height the more light/power will be needed to achieve a given illuminance, but a more uniform result will be obtained.
2. Layout. Columns can be on just one side of the road or both; pairs of columns can be either opposite each other or staggered.
3. Spacing. The longer the spacing, the lower the level of illuminance and the more uneven/patchy. However, small spacing result in greater cost and are not always practical.
4. Lamp type. Although tungsten and tungsten-halogen lamps are cheap and require no special starting and control gear, their short lives and low efficiency rule them out for anything but the smallest village installation. Discharge lamps offer long lives and high efficacy. Further information about the various types is given at the end of this chapter. Once the type of lamp is decided the correct power is chosen to give the required lighting level.

   The comments in the previous chapter on light emitting diodes should also be recalled. A trial roadway luminaire containing 25 3-watt diodes has recently appeared, and this is a development to watch. In theory such a luminaire has much to offer a developing country - simple operation, very long life and low maintenance.
5. Luminaire. The actual luminaire chosen has, obviously, to be suitable for the lamp type and power; the detailed information provided by commercial suppliers can be

relied upon for this. Manufacturers also provide information on intensity distributions, although this is more usefully incorporated in software which enables the performance to be studied in a variety of situations (see below). Suppliers also give practical information on the luminaire's resistance to penetration from dirt/dust and water (its IP rating).



Definition of terms commonly used in road lighting geometry.

In deciding on lamp power it must be remembered that they age and reduce an installation's performance. This can be significant- for example, after 24 months a typical high pressure sodium lamp burning 4000 hours a year will be giving 94% of its initial output, and a typical high pressure mercury halide lamp only 76% (assuming 4000 hours use per year). More information on this is given at the end of this chapter.

Eventually, of course, all lamps fail. The maintenance of installations is dealt with in Chapter 6.

5.5 Calculations - the actual installation

Using reflection factors or tables for typical road surfaces in conjunction with the intensity distributions of the chosen luminaires, it is possible to calculate the illuminance and luminance patterns given by a particular arrangement of luminaires above the road surface. This is a time-consuming process and realistically has to be done by computer. Fortunately the programs to do this are readily available - some are provided freely by the luminaire manufacturers.

Typically the user has to enter details of the road, such as its width and an estimate of its general reflection characteristics (chosen from a classification of internationally agreed typical surfaces: one index refers to the general "lightness" or "darkness" of the surface, the other to its "shininess"). It is then possible to try a multitude of combinations of layout, spacing, mounting height, bracket projection and luminaire/lamp type until the desired luminance (or illuminance) performance is attained.

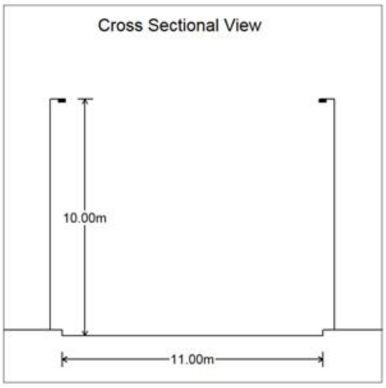
An abbreviated example of the printout from such a program is shown on the following page; the full printout includes a shaded and colour-coded map of the luminance and/or illuminance patterns on the road surface.

Such programs can also be a valuable teaching aid to show the effects of changes in the various quantities which are at the designer's disposal, and also the effects - such as changes in the road surface - which are not.

The simpler programs described above are, strictly speaking, applicable only to straight roads. They can, however, be used to a good approximation for moderate bends. Single-sided arrangements should be used, with the lanterns on the outside edge of the road, and the spacing should be gradually reduced as the radius of the bend decreases.

Roadway Report Summary

Layout



Road Data

Calculation Grid	CEN Illuminance
Width (m)	11.00
No. of Lanes	2
Road Surface	R1
Q0	0.07
Left Footpath(m)	0.00
Right Footpath(m)	0.00

Main Lighting

Column Data

Configuration	Staggered CEN
Spacing (m)	32.00
Height (m)	10.00
Tilt (deg)	0.00
Left Setback (m)	0.50
Left Outreach (m)	0.50
Left Overhang (m)	0.00
Right Setback (m)	0.50
Right Outreach (m)	0.50
Right Overhang (m)	0.00

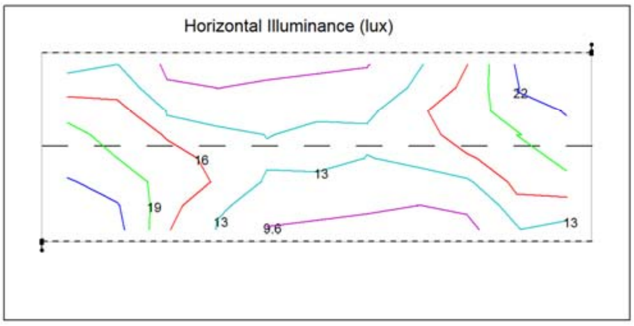
Luminaire Data

Supplier	demo
Type	150W Main road posn 5
Lamp(s)	SONT150
Lamp Flux (klm)	16.50
File Name	mr150e.pmo
Maintenance Factor	0.95
Lum. Int. Class	G1

Results

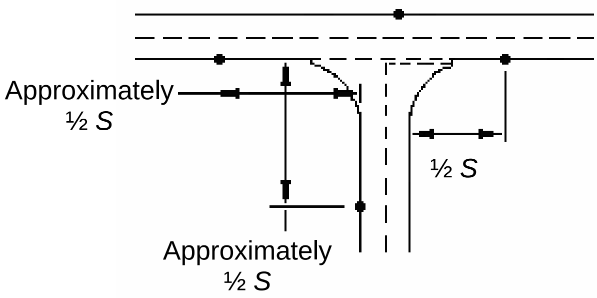
Main

Eav	14.90
Emin	7.99
Emax	27.02
Emin/Emax	0.30
Emin/Eav	0.54

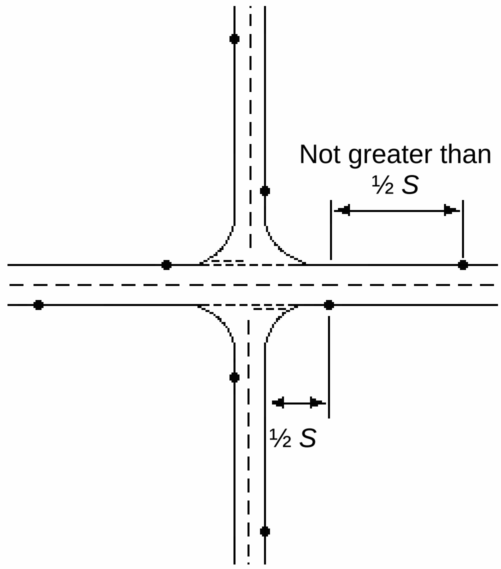


Example of printout from a typical illuminance calculation program.

At T-junctions a lantern should be sited on the major road opposite the exit/entrance of the minor road. This will alert drivers on the latter to the presence of the junction, and help reveal turning traffic to drivers on the major road. In a similar way lanterns should be sited on the nearside of the arms of crossroads to reveal crossing traffic.



S is the design spacing for the major road



S is the design spacing for the major road

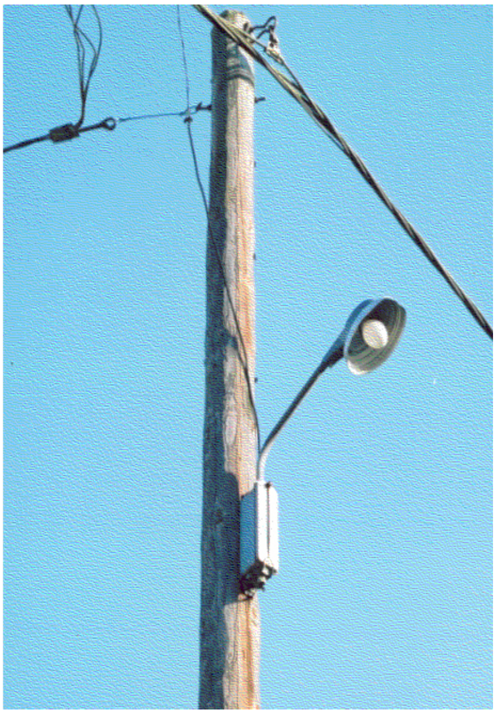
At roundabouts, the columns should be sited on the outer radii. This discontinuity in the lines of lanterns helps to emphasise the presence of a roundabout, an effect which can be enhanced by increasing the lighting level (by about 50%) and even by changing the lamp type to give a different colour appearance.

Highlighting a small part of the overall road network can be used at places where large numbers of pedestrians - or animals - habitually cross the highway, even if these are not officially designated and marked as crossings.

5.6 Open luminaires

Modern luminaires are precision items. The discharge tube, increasingly compact, has to retain its position with respect to the highly polished reflectors and the cover, particularly if the latter has any refracting elements on its inner surface. The sealing gasket has to be highly effective to keep out dust, dirt, insects and moisture. Modern sealed beam units can now achieve sustained IP66 ratings for some twenty years, but the majority of luminaires in service will be more vulnerable to poor servicing. Inevitably seals will be disturbed when the lamp is replaced. (see Chapter 6, Maintenance). There is the danger that the luminaire will not then be sufficiently airtight, especially if the maintenance crew is poorly trained. The lantern's optical surfaces will then gradually deteriorate.

If it is expected that maintenance will be, at best, perfunctory, then an alternative is to use an "open" luminaire, in which dirt cannot accumulate. This could be a cut-off lantern with its horizontal cover removed, or a simple white bowl reflector protecting the lamp. As only the light flux from the lower half of the lamp reaches the road (and that in a less controlled manner) the overall efficiency is obviously inferior to a "proper" luminaire, but at least the output is maintained as long as the lamp is burning.



5.7 Reducing light pollution

There has been growing concern in recent years over the growth in the amount of light which is scattered upwards into the night sky. Some of the world's larger cities exist at night under a blanket of this "sky glow", a form of environmental pollution.

This light is not only wasted - it can be positively harmful. Animals and wildlife in national parks and game reserves can be disturbed by it. Sensitive optical astronomy can be upset by it - many major high-class observatories are to be found at high altitudes in sub-tropical countries. It is worth noting that the light from the low pressure sodium lamp is monochromatic, and can be filtered out by astronomers to minimize interference.

The CIE has classified locations into four "environmental" zones. The strictest category, E1, is for national parks and "dark landscapes". Within such a zone there should be no flux from a luminaire going directly into the sky, and the only vertical illuminance permitted into windows should be a maximum of 1 lux coming from a public roadway lighting installation.

<u>Summary characteristics of discharge lamps for roadway lighting</u>

The following table shows the basic characteristics of discharge lamps in common use.

Lamp type	**Efficacy (lm/watt)**	**Colour rendering**	**Average life (hrs)**
Low Pressure Sodium- SOX	200	None	16000
High Pressure Sodium-SON	120	Low	20000
High Pressure Mercury-MBF	60	Moderate	20000
High Pressure Mercury + Halides-MBI	90	Good	20000
Ditto, with ceramic arc tubes-CDM	90	Very good	10-15000

Notes: Colour rendering is not highly important for roadway lighting, except in sensitive urban centres and/or areas with large numbers of pedestrians. So if energy efficiency is the over-riding factor low-pressure sodium lamps (SOX) have much to offer. However, they are relatively large lamps which require correspondingly large luminaires to house them.

They are being superseded by physically smaller high-pressure sodium lamps (SON), which give a "golden" light with modest colour rendering.

Less efficient are high-pressure mercury vapour lamps (MBF). The newest versions of these incorporate metal halides to increase life and colour rendering (MBI). When these have ceramic, rather than quartz, arc tubes they are designated CDM.

The falling-off in light output which inevitably takes place differs for these lamp types. Typical figures over 3 years, running at an average of 4000 hours per year, are shown in the following table.

Lamp type	12 months	18 months	24 months	30 months	36 months
SOX	0,98	0,96	0,93	0,90	0,87
SON	0,98	0,97	0,94	0,91	0,90
MBF	0,87	0,83	0,80	0,78	0,76
MBI	0,82	0,78	0,76	0,74	0,73

Lamp technology continues to change, and the information in the tables can only be approximate. Local choice will obviously be affected by cost and availability.

6. MAINTENANCE

All the aids to safer night-time driving - markings, vehicle lights, roadway lights - deteriorate with time and use. Roadmarkings wear out, the lamps in vehicle and street lights fail, luminaire reflector and cover materials deteriorate, and dirt accumulates inside and outside the various fittings.

Responsibility for maintaining the performance of roadmarkings and streetlighting falls to the public authorities. The upkeep of vehicle lighting, whether motorised or non-motorised, falls either to fleet operators or private individuals. This chapter concentrates on the maintenance of fixed roadway lighting, as this is the most demanding in terms of organisation and manpower.

6.1 Maintenance of fixed roadway lighting

A well-designed lighting installation is a highly visible public asset. To sustain its value any failed lamps need replacing, the optical components need regular cleaning, and the electrical equipment needs routine testing and maintenance. Failure to do this not only negates the careful design work, but leads to public dissatisfaction and a higher risk of night-time accidents.

6.1.1 Lamp life and replacement

Lamps gradually give less output as they age (see previous chapter). In addition to the gradual loss of light output, out of a large sample of any lamp type there will be a fraction which fail prematurely, i.e. when the lamp is still emitting adequately. Typical lamp survival factors for the four major lamp types are shown below (assuming 4000 hours use per year):

Lamp type	12 months	18 months	24 months	30 months	36 months
SOX	0,92	0,86	0,80	0,74	0,62
SON	0,98	0,96	0,94	0,92	0,89
MBF	0,98	0,97	0,94	0,92	0,88
MBI	0,93	0,91	0,87	0,82	0,76

Before finally failing, lamps often start to "cycle" - they go on when cold but self-extinguish after burning for a short time. The lamp cools down, and then re-ignites. Cycling is difficult for maintenance patrols to identify (see next section), but can be assisted by using ignitor circuits which switch out if the lamp goes out without there being an interruption in the power supply.

There are two major approaches to lamp replacement:

1. <u>Replacing individual lamps as and when they fail, and only when they fail</u>. This has an intuitive appeal to developing countries but it can, especially if manpower costs are high, be a more expensive option. It also has the disadvantage that many lamps in an installation could be approaching failure and giving out significantly less light than the quantities assumed in designing the original installation.
2. <u>Replacing all lamps in a group with new lamps after a fixed period</u>. This is usually the most cost-effective approach, but should be modified to exclude lamps which have been recently replaced as a result of random failure. Alternatively, such lamps (carefully date-coded) can be recovered and used for future random replacements.

A practical compromise is to use only new lamps for "spot" replacement during the first 70% of the time interval between group replacement. Good lamps which have burnt for less than 30% of their rated life can be used for spot replacements in the remaining period and then discarded at the next group replacement.

Because of the possible premature failure of new lamps, an installation which has had group replacement should be inspected at night after some 100 hours of operation.

6.1.2 Installation inspection

Although the public can be encouraged to report lighting failures in residential areas, more generally it is necessary to organise night-time inspections. Patrols can be on foot, bicycle or slow-moving car. They should simply note failures in readiness for repair during daylight hours.

The level of sophistication of recording faults can vary from simple notepad to hand-held computer/data recorder. The important element is the accurate and timely collection of the information and its transmission to the management of the repair work. It also forms an important part of the records of the general health of an administration's lighting. As a rough guide, central records should detail:

1. identity number (as recorded on the pole or column);
2. location;
3. mounting height and bracket outreach;
4. type of mounting (column, pole, wall);
5. lantern type;
6. light source type and wattage;
7. control gear, switching equipment, fuse details, etc.;
8. electricity supply;
9. routine maintenance and bulk lamp change dates (where applicable).

The daytime repair teams should be able not only to replace failed lamps but also have the expertise and equipment to diagnose and cure simple failures of control gear and other electrical components on site. (A simple flow chart for fault analysis is offered at the end of this chapter). Lanterns which cannot be treated should be returned to centralised workshops for renovation or replacement of major components. Again, good record-keeping is essential for cost-effectiveness.

6.1.3 Cleaning of luminaires

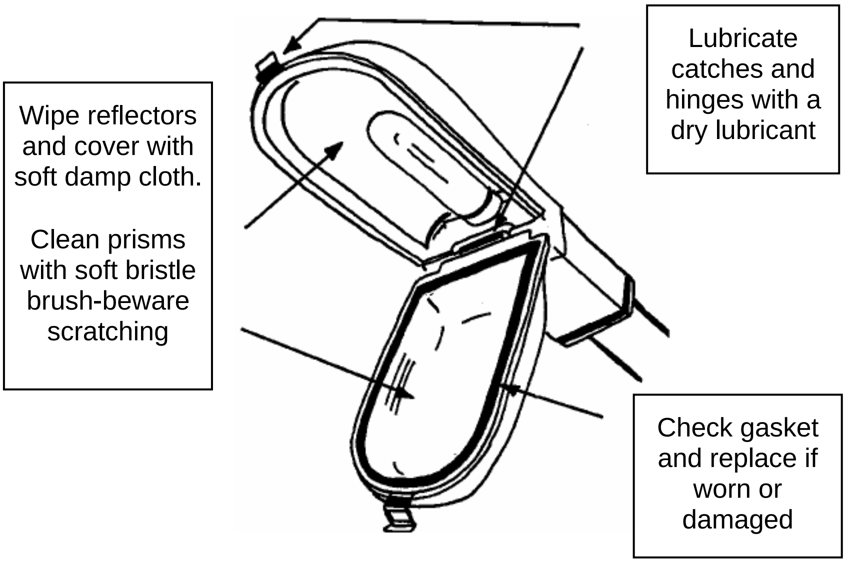
The extent to which air-borne dirt and pollution reduce light output depends on the effectiveness of the luminaire's sealing (its IP rating) and the quality of the environment. The following table shows some typical dirt depreciation factors.

IP Rating	**Environment**	**Cleaning Cycle**				
		12 months	18 months	24 months	30 months	36 months
IP2	Clean	0,90	0,90	0,79	0,78	0,75
	Average	0,62	0,58	0,56	0,53	0,52
	Dirty	0,53	0,48	0,45	0,42	0,41
IP5	Clean	0,92	0,91	0,90	0,89	0,88
	Average	0,90	0,88	0,86	0,84	0,82
	Dirty	0,89	0,87	0,84	0,80	0,76
IP6	Clean	0,93	0,92	0,91	0,90	0,89
	Average	0,92	0,91	0,89	0,88	0,87
	Dirty	0,91	0,90	0,88	0,86	0,83

As with the loss of lantern output because of lamp deterioration, the likely loss from dirt and pollution should also be allowed for in the initial installation design. It is self-evident that choosing good quality lamps and well-designed lanterns in the first place is always a sound investment. The table confirms the importance of good lantern sealing in "dirty" areas, which include regions which suffer from frequent dust storms.

However, if cleaning is likely to be neglected and poor maintenance seems inevitable then there is an argument for simple open lanterns. In highly polluted areas a poor quality sealed lantern with badly maintained/faulty gaskets can become so internally soiled that its light output becomes less than that of an open lantern. Even if the reflectors in an open lantern deteriorate completely, the basic lumen output from the lamp itself is still available, even if not properly controlled.

The main practical points for cleaning teams are summarised in the following figure.



In addition to caring for the lantern, whilst on site maintenance crews should be alert to the general "health" of the columns. They should make good or report any corrosion, damage to foundations (is the column still truly vertical?), damage to the access door, or deterioration in the mechanical condition of any outreach bracket.

Checks on wiring and electrical equipment are also necessary, but it is not the place of this manual to go into the details of electrical maintenance. It is also outside the remit of this document to give on-site safety procedures common to all safe highway working.

It is, however, worth mentioning that a simple illuminance meter is a useful tool for any professional in a highway team charged with responsibility for its lighting. Encouraging an organisation to check illuminance values over time at marked positions in an installation (e.g. 100 hours after a bulk replacement and then every 12 months) can give useful information on installation performance and maintenance factors for future designs. At the personal level it engenders professional pride and interest in the job.

6.2 Maintenance of vehicle lighting

All the lights on a vehicle - headlights, running lights, signalling lights, etc. - should be checked regularly. It is not sufficient to rely on mandatory annual inspections, even in those countries which have them. It is a useful discipline for individual drivers to check that all lights are working and clean when they make other routine checks on their vehicles, such as tyre condition, engine oil level and radiator coolant. Any lights which have been damaged or in which the reflectors are badly corroded should be replaced.

The importance of accurate headlight aim has already been stressed in Chapter 4, together with a description of the ways it can be checked.

Some countries make the carrying of spare lamps a legal requirement, and this is clearly good practice. As a minimum, a spare headlight lamp and a spare rear running light lamp should be carried. Drivers should be warned against trying to use the "wrong" lamp in a headlight, even in an emergency, as the results are likely to be either insufficient illumination or excess glare. If only one working lamp is available in such a situation, either front or rear, the offside light should be the priority.

Non-motorised vehicle lighting systems are particularly prone to failure, partly because of neglect and partly because of their inherently less robust engineering. Battery powered lights need regular checking, preferably during daylight. Users should guard against leaving used batteries in place, as leakage can rapidly corrode and weaken connectors and switches.

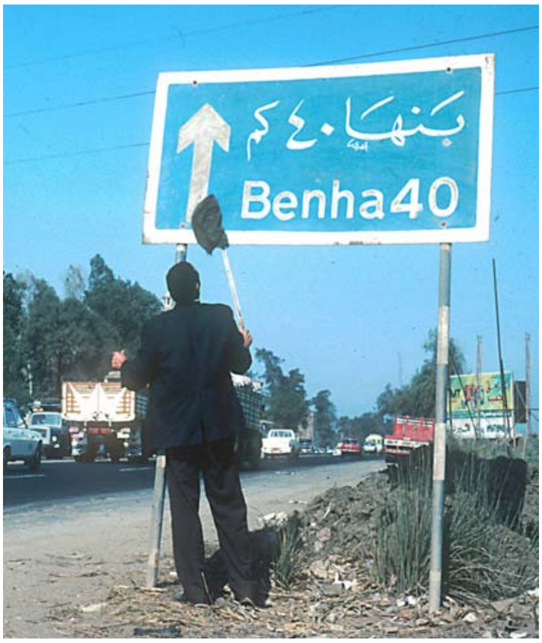
This type of practical guidance has to be disseminated through a variety of channels, and is included in the Appendix.

6.3 Maintenance of signs and road markings

It is self-evident that signs need regular cleaning, and that road markings need regular renewal, if they are to retain their effectiveness. However, it is virtually impossible to give quantitative guidance on the frequency of such maintenance, as conditions vary so greatly. Factors such as overall levels of pollution, traffic densities, positions of signs, the type and position of road markings (and their initial quality), all play a part in determining their useful life.

What is not in doubt is the value of signs and markings, particularly reflectorised ones, in night-time driving. Their upkeep should be an important part of the regular maintenance of the highway as a whole, and its organisation and management integrated with it as far as possible.

Portable retroreflectometers are available which give an accurate measure of the quality of road markings in terms of the ratio of the reflected intensity to the incident light. They can be used for both day and night visibility. Simpler machines rely on a visual comparison with internal reference standards.



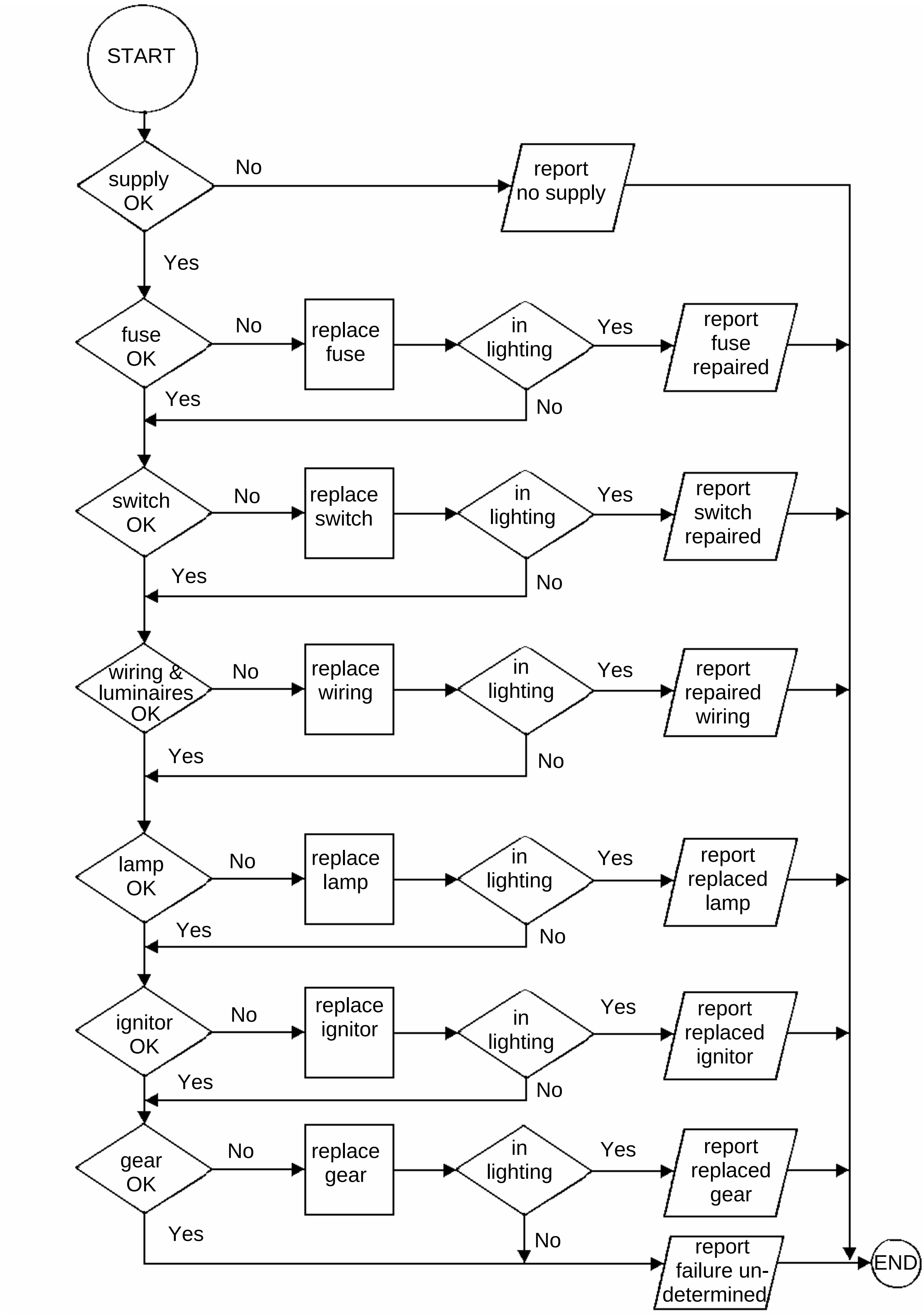
Similarly there are portable instruments which can measure the performance of individual markers, signs, studs, etc., but it is more common to make assessments visually at night, using agreed criteria based on how "far down the road" they can be seen by the vehicle's headlights.

In the likely absence of quantitative equipment, a more practical approach is to organise night-time inspection tours in a vehicle equipped with average-quality lighting, and for an experienced observer/traffic engineer to note the effectiveness of all signs/markings on a particular route. It can be useful for the vehicle to carry with it small samples of markings on short lengths of boarding (and even new sign material samples) made at the same time as the installations under inspection, but kept safely at the highway department's headquarters.

This approach is very effective in noticing missing centre-line and edge markers. It also has the advantage of showing up failures in the retroreflection of markings which in the daylight may still appear adequate. This commonly occurs with markings which have been made retroreflective by having ballotini scattered into their surfaces.

Good record-keeping during these night-time inspections is an obvious requirement. The data can usefully be combined with the information on the quality of the public lighting installations to give an overall picture of the "night-time visibility" health of an administration's road network.

Not only will this be a valuable management tool, it will also assist the scientific investigation of night-time accidents.



Flow chart of test procedure for analysing faults in a typical lighting system
(from the ILE Manual of Road Lighting in Developing Countries)

APPENDIX. MATERIAL FOR ROAD SAFETY CAMPAIGNS

A.1 All drivers

It is hard to appreciate how little of the roadway ahead, and its surroundings, can be seen at night. Most of the things the eyes are good at doing deteriorate at night.

- If there is little traffic use your main beams, but dip in plenty of time when another vehicle comes towards you and when you come up behind another vehicle going your way. If you overtake, stay dipped until you are level with the other vehicle.
- Slow down if you are dazzled by oncoming lights. Concentrate on the nearside edge of the road. Avoid looking directly at the oncoming headlights, even for a very short time.
- Keep your headlamps well-aimed. If the normal setting is upset by loading your vehicle very heavily for a night-time journey (either at the front, or more commonly at the rear), re-adjust your aim.
- Keep your lamps clean. A layer of dead insects and dirt absorbs and scatters precious light: you need all the light you can get. In the same spirit keep your windscreen clean. A dirty or heavily scratched windscreen not only absorbs light but in the face of oncoming lights creates a luminous veil which is hard to see through.
- The light coming back from the road surface and other features is low in intensity. Do not reduce it further by wearing sunglasses or using tinted visors. Avoid gadgets which claim to reduce glare from oncoming headlights. Some certainly can, but at the expense of reducing the effectiveness of your own lighting.
- Do not drive with "working" lights on in your vehicle. If it is unavoidable (for example, in commercial delivery vehicles), make sure they are of low intensity and carefully shielded to avoid direct light in the driver's eyes and reflections in the windscreen.
- Headlamps are precision items. Do not attempt to fit a replacement bulb which is not the correct one for the unit. Ideally a set of spare bulbs should be carried, but if one headlamp fails and a spare cannot be got immediately it is advisable to make sure that it is the offside lamp which is working.
- Headlamps are obviously important for you to see, but your rear (red) lamps are equally important for you to be seen. Remember that your position and relative speed are largely judged by them - make sure they are clean and both working. Your indicator lamps - front and rear - are also important in the dark when other road users have fewer clues as to intended actions and movements.
- Make sure that your vehicle wiring and contacts are sound (particularly for Do-It-Yourself additions). A fall in voltage of half a volt at the lamp can reduce its light output by about 14%. If you have a trailer check carefully that all interconnecting cables are working properly.

A.2 Cyclists and motorcyclists

Most of the general advice to motorists applies to you also, but remember your "vehicle" lights are, if anything, more important in making your presence known. Make sure they are clean and working: battery-powered cycle lamps are notorious for failing just when needed.

Even if your bike/motorbike carries reflectors, boost your visibility by wearing something reflectorised or, as a minimum, something light-coloured.

A.3 Pedestrians, non-motorised vehicles, etc.

Help other road users to see you. Unless you are a driver it is hard to realise how difficult it can be to see pedestrians in the roadway at night. In particular, young children cannot understand how a car or lorry with two bright shining "eyes" can fail to "see" them.

Reflective materials (armbands, sashes, waistcoats and jackets with stripes, etc.) can be seen by drivers using headlights up to three times as far away as non-reflective materials.

But be careful not to give children the idea that wearing a reflectorised toggle gives some magic protection!

If reflectorised materials are not available - and lamps cannot be carried - then the minimum is to try and wear some light-coloured object of clothing, preferably on the lower part of the body where the intensity of dipped beams is greatest. Similarly, the rear of unlit carts and trailers should carry white/light coloured panels of material (even temporarily) as near to the ground as practicable.

An organised group of pedestrians using the road at night should think of itself as a slow-moving vehicle. The leader at the front should carry a white light and lookouts at the back a red light. If possible, people on the outside should also carry lights and wear reflective clothing.

All road users…….**BE SAFE, BE SEEN.**