SIDE LIGHTS AND LOW-BEAM HEADLIGHTS IN BUILT-UP AREAS

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Institute for Road Safety Research SWOV, The Netherlands

Contents

Foreword

The question whether side lights or low-beam headlights*) are to be preferred regarding road safety in built-up areas has existed for years in the Netherlands and in other countries. Views differ from country to country.
Extensive research has been carried out in Britain with a view to answering this question.
In Birmingham in 1962, drivers were asked to use 'dipped headlights' on all roads in town [1]. By comparing accident statistics before, during and after this change in customary car lighting, an attempt was made to assess its effect on road safety. The assessment by the Road Research Laboratory, however, was not sufficiently decisive [2].
For this reason, and because the traffic conditions, the standard of street lighting and the traffic structure in Britain differ greatly from those in the Netherlands, it was decided to repeat the trials with low-beam headlights and assess the effect on road safety in the Netherlands.
A request was accordingly received by SWOV from the Central Police Traffic Committee (CPVC) at the end of 1964. The Minister of Transport and Waterways gave instructions to carry out the investigations.
A year earlier, an enquiry had been made in Haarlem, organised by the police and city council, which had also proved inadequate for drawing any conclusions. In the same year, 1964, after talks with the police authorities in Utrecht, Amsterdam, Groningen and The Hague, Utrecht was decided upon as the place for the SWOV trials. The other cities would be used as 'controls'.
An accident-recording system was agreed upon with the police. A number of additional questions were added to the normal accident form. Processing of these data ultimately caused a lot of difficulty because the forms had not been completed in a uniform fashion. This made them unsuitable for mechanical processing. Consequently, nearly all forms had to be analysed one by one by the few workers SWOV had available at that time. Besides this, SWOV began to doubt whether the statistical processing method used by the Road Research Laboratory, which had also been chosen for the Dutch research so that the results could be compared, was really the most suitable method. These doubts were substantiated by an article by the Australian Road Research Board demonstrating the weaknesses in statistical processing of the British research [3]. A different method was therefore sought. After the new statistical processing of the Dutch trials was completed at the end of 1967 it was found, similarly to Britain, that such trials give no definite answer to the question whether side lights or low-beam headlights are better in built-up areas. Not only the possibilities, but especially the limitations of statistical study based on accidents must be appreciated. It can merely answer the question what is the effect on road safety of changing over from side lgihts to low-beam headlights in the conditions existing at a given moment? This means that such study, even if it definitely answers the question 'whether one is better than the other', gives no forecast, or hardly any forecast about other, uninvestigated possibilities. These may be, for instance, the introduction of brighter side lights or a different standard of street lighting or a change in traffic structure.
SWOV therefore already decided during the statistical research, to carry out theoretical and experimental research on an analytical basis, in order to make predictions for a possible future situation. Both car lighting systems were assessed and their influence on road users' perceptiveness was examined. Experiments were made relating to assessment of distances to and speeds of cars approaching in the dark by a number of observers. The degree of glare by vehicle headlights in various situations was analysed.
All this research is described in the present report. The results have led to certain conclusions and final considerations.
These considerations cannot be regarded as conclusions from the research, but they do arise from information thereby acquired.

*) Low-beam headlights is used as a synonym to passing beams, short beams, dipped headlamps, etc.

The report 'Side lights and low-beam headlights in built-up areas' has in the final instance been compiled by Dr. D. A. Schreuder (Basic Research Department SWOV). The statistical research was carried out by J. C. A. Carlquist, A. Blokpoel and J. van Steenis (Statistics and Documentation Department SWOV). Advice on statistical processing methods was given by Professor J. W. Sieben, of the Delft University of Technology and L. B. Verdoorn, senior scientific officer at the Institute for Crop Variety Research, Bennekom. Advice regarding the methodological aspects was given by D. J. Griep, research psychologist (Human Factors Department SWOV). The experimental research was carried out by the Lighting Laboratory of N.V. Philips' Gloeilampenfabrieken, Eindhoven, and was led by Dr. D. A. Schreuder. The research as a whole was completed at the end of 1968.

The research into 'Side lights and low-beam headlights in built-up areas' was the first practical research undertaken by the then two-year old SWOV. The experience gained made it clear that quicker results would have been obtained if the research had been organised differently. If the analytical research had been done first, the statistical research in Utrecht and in the 'controls' could have been more differentiated in certain respects which analytical research showed to be of influence upon accident hazards.
This opinion, which has been confirmed by experience gained in research projects also commenced in SWOV's early stages, has led to a method whereby every project commences with analytical research resulting in a descriptive report. On the basis of this report, a decision may be taken for further research. This method has now been established as a system of network planning.

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Summary

1. With well lighted streets, low-beam headlights make no noticeable contribution to perceptibility of objects. With poorly lighted streets, low-beam headlights make a positive contribution without leading to an adequate perceptibility level for objects of which small details have to be observed. Cyclists and pedestrians are such objects. Side lights make a negligible contribution to this (Section 2).

2. Glare caused by approaching cars' low-beam headlights is unacceptably serious with all prevailing standards of street lighting, especially if there are a large number of approaching vehicles. Side lights hardly ever cause glare, but in many cases are not conspicuous enough (Section 2).

3. If the quality of street lighting is better, more motorists voluntarily use side lights (Section 3).

4. The increase from about 35% to about 80% low-beam headlight drivers in the built-up area of Utrecht during the experiments had no demonstrable effect on the total number of traffic accidents. Nor were accident hazards in the dark (the daytime/night-time ratio) significantly changed (Section 3).

5. The simultaneous use of side lights and low-beam headlights is misleading and confusing and may be a major source of traffic accidents in the dark. In view of the results given in 4, the actual percentage of low-beam headlights and side lights apparently has little effect (Section 3).

6. The low-beam headlights standardised in most West European countries (the E lamps) are in good agreement, though there may be considerable differences due to mal-adjustment and obsolescence.
There are, however, big differences between car side lights. Many are not conspicuous enough. This is concluded, inter alia, from the disproportionately small number of cases involving low-beam headlight drivers and pedestrians (Section 3).

7. Even a low intensity of side lights suffices for detectability of a single car under laboratory conditions. Interactions between side-light drivers and pedestrians are therefore attributable especially to the existence of distracting light sources, for instance other vehicles with high intensity lighting. (Section 4). See also 5.

8. The behaviour of pedestrians crossing roads (expressed as desirable crossing time and frequency of erroneous decisions) is not measurably dependent upon the intensity of the car's lights under laboratory conditions with a single car approaching along an otherwise clear road. Nor does it depend upon the average standard of street lighting. Faulty decisions in practice—especially wrongly crossing when a car with side lights is approaching—must therefore be the consequence of disturbing influences, such as cars with high-intensity lights. (Section 4).

Conclusions

The above has indicated that both low-beam headlights and side lights have certain drawbacks. It is advisable to seek a lighting system for the front of motor vehicles which lacks these drawbacks but preserves the advantages. This can, for example, be achieved with a light of an intensity between the present low-beam headlights and side lights, guaranteeing adequate conspicuousness with an acceptable degree of glare. The use of such 'new style side lights', however, implies that the public lighting must also be taken into account. On the other hand, alternatives should be investigated as well.

Final considerations

The question of which are safer, side lights or low- beam headlights, arises especially on roads with mixed traffic in both directions. It cannot be answered without taking the street lighting into consideration.
The experimental results, referred to in point 4 of the summary indicate that in the present situation (i.e. with the present quality of public lighting, and of motor vehicle lighting, and with the present composition and structure of traffic) unsufficient grounds do exist to make a choice between either obligatory use of side lights or low-beam headlights.
On roads where kinds of traffic are divided, with one-way traffic or with separated lanes, street lighting has to satisfy less stringent standards and the uniform use of side lights might be acceptable as long as no allowance has to be made for the existence on the road of objects such as cyclists and pedestrians.
In urban conglomerations where the roads do not satisfy these conditions, a solution might be possible by providing all traffic roads with good lighting (for example a road-surface luminance of about 0.5 cd/m^2) combined with car lighting of an intensity between that of present low-beam headlights and side lights.
For this purpose it is desirable to create 'new style' side lights for motor vehicles, with a luminous intensity between say 30 and 50 cd. It is desirable to keep these limits fairly close together, with a view to the necessary uniformity. More precise definition is required as regards shape, colour, brightness distribution and placing of such side lights on vehicles.

Research

1. Introduction

Statistics indicate that in the Netherlands over 20% of all road accidents every year occur during dusk or darkness [4]. No data are available for the Netherlands regarding the number of accidents per vehicle-kilometre during daytime and night-time. Based, inter alia, on American figures [5], however, it can be assumed that accident risks in dusk and darkness are about three times as great as in daytime. Reduced visibility, also combined with factors affecting the driver (such as fatgue, alcohol consumption), is likely to have an effect on the occurrence of these accidents.
The influence of reduced visibility on road safety has always been taken for granted. Vehicles were provided with lights, and street lighting in busy roads was soon adapted to motor traffic. The development of vehicle and street lighting was directed by lighting technicians with wide experience of visibility standards. The requirements that were (and are) imposed are evident, among other things, from the ingenious but complicated construction of the standardised car headlamp on the West European continent.
The possibility of combining a high-beam headlight and a low-beam headlight in a single lamp took many years of research. Development of these car headlamps was based on *correct* use under *ideal* conditions. Practice proves, however, that there is no question of correct use in many cases. The figures for car lighting campaigns speak volumes in this respect. Out of 18,477 cars checked by the Koninklijke Nederlandse Toeristenbond ANWB (Royal Dutch Touring Club ANWB) in 1968, 93% had their headlamps to be adjusted. Of these, 59% were beamed too high [6]. Following a campaign by the Verbond voor Veilig Verkeer (Netherlands Road Safety Association) in 1968, in co-operation with Volkswagen dealers, it was announced that 61% of Volkswagens and 70% of other cars inspected had their lights wrongly adjusted [7]. Furthermore, the non-stipulated use of either side lights or low-beam headlights in built-up areas may bring about a very ragged and obscure traffic pattern, which is also aggravated by the great variations in side-light intensity. It is therefore understandable that the authorities are being faced increasingly with the question whether standardised car lighting is necessary. In a number of countries, some of them in Western Europe, such considerations have in fact led to regulations being made.
There is, however, no question of unanimity in the different countries. As regards legislation on motor vehicles lighting in built-up areas, three main categories can be distinguished [8].
1. The use of parking or side lights is forbidden during driving (includes USA, Czechoslovakia, Belgium). In some other countries the general use of low-beam headlights is strongly recommended (e.g. Federal Germany).
2. Driving with low-beam headlights is compulsory only if street lighting is inadequate. If street lighting is adequate, side lights are stipulated (includes France, Italy). The problem in these cases is how 'adequate street lighting' is to be clearly defined for the road user.
3. There are not regulations regarding the use of side lights or low-beam headlights; the road user is free to choose himself (includes the Netherlands, Denmark, Great Britain). These countries do, however, recommend using side lights in well lighted streets and low-beam headlights only in poorly lighted streets.

Regulations and recommendations, and their enforcement, have considerable influence on driving habits, i.e. on the use of side lights or low-beam headlights.
In the USA nearly all drivers use low-beam headlights in towns. In Belgium and Federal Germany the percentage of low-beam headlight users is also very high. In France and Italy, nearly everyone uses side lights in the cities. In the Netherlands, where road users make their own choice, there is a big difference between the various towns.
There are typically 'side light towns' and typically 'low-beam headlight towns'. In some cities in the west of the country there is a pronounced preference for side lights. But in Groningen and Eindhoven, fo instance, there is a preponderant use of low-beam headlights. The confusion arising from the differences between Dutch towns led to instructions being given in 1964 for research into the effect of side lights or low-beam headlights on road safety. After some brief preparations, statistical research was started at the end of the same year. Experimental research followed in 1966.

2. Analysis of the problem

2.1. Introduction

The question whether it is preferable in built-up areas, i.e. where there is street lighting, to use low-beam headlights or side lights is primarily a problem of road safety. An unqualified answer can only be given by investigating the effect of the type of vehicle lighting on accident risks (statistical accident research). Accident risks, however, are influenced not only by the type and standard of lighting but also—and presumably much more so—by many other factors. Moreover, statistical research only allows a choice to be made of investigated (i.e. existing) systems. Lastly, no statistical explanation can be given for the occurrence of certain types of accidents. In view of this, it is opportune to adopt the plausible but unproved assumption that correct and safe road behaviour requires obstacles, vehicles, etc. to be perceptible. It must next be ascertained what fundamental knowledge is available regarding physiological, psychological and technical aspects of lighting, and their influence on the perceptibility of objects. After this, it can be examined in which respects available knowledge is inadequate, and where supplementary research is required. It can be deduced from the completed fundamental knowledge to what extent observation of objects on or near the road depends on the given conditions. These conditions also include lighting. When these dependences are known, statistical accident research can be used to decide what type of vehicle lighting is preferable in built-up areas.

2.2. Perceptibility

Whether an object is perceptible depends on its nature, its surroundings and the observer. Whether it will in fact be perceived in the given surroundings also depends, and very much so, upon what the observer is doing and his personal attitude. Before these matters can be discussed, some concepts require definition.

2.2.1. Visibility

Visibility (or detectability) is defined as the property of an object to indicate whether its presence can be established by a 'normal observer' in the given conditions, provided there is no distraction whatsoever, and the observer can therefore concentrate entirely upon his duty to observe. The decisive factors for visibility or non-visibility of an object are the normal psychophysically determinable threshold values of, for instance, contrast sensitivity.

2.2.2. Conspicuousness

Conspicuousness is defined as the property of an object to indicate whether its presence can be established in the given conditions allowing for all potential sources of distraction, particularly the observer's duties as a road user (motorist, cyclist, pedestrian, etc.). Conspicuousness is governed partly by the extent to which the stimuli are stronger than those corresponding to the threshold values. Conspicuousness can be defined partly as the extent 'supra-threshold'. It also depends on how the object stands out in colour, shape, brightness, etc. against other nearby objects. Lastly, a part is played by the expectation whether the object will be encountered at that place. Conspicuousness can only be defined quantitatively if the conditions are fully known.

2.2.3. Recognisability

Recognisability is defined as the property of an object to indicate whether its inherent nature and characteristics can be determined in the given conditions, allowing for all potential distractions. A very great factor in recognisability is of course the extent to which the observer is familiar with the object's nature and characteristics.

2.2.4. Localisation

Localisation is defined as the property of an object to indicate whether the observer can establish its location and if necessary its movements and changes therein. Localisation presupposes adequate visibility, conspicuousness and recognisability.

2.2.5. Object

An object is defined as any person and any thing whose perceptibility is or may be important to road safety. An object constituting an immediate danger to traffic is sometimes called an obstacle.

2.2.6. 'Normal observer'

A normal observer is defined as a (hypothetical) person whose visual capacities are such that, for all physiological characteristics (acuity of vision, quickness of perception, contrast sensitivity, etc.), it gives a value exactly the same as the average for the entire road-user population.

2.3. Purpose and function of street lighting

The two purposes of artificial lighting for road traffic are: 'Promotion of safety and smooth traffic flow at times when natural light is deficient'. The present report is confined to the first purpose: promotion of safety.
To achieve this purpose, road users must be supplied with sufficient visual information—lighting of course playing an essential part. This information relates to:
1. the direction of the road (road surface) relative to the drivers' direction (course, route);
2. the presence of objects of importance to safety and smooth movement in the driver's direction; such objects can be divided into three basic categories:
a. other moving road users or their vehicles travelling in such direction that there is a risk of collision;
b. stationary objects in (or close to) the direction being travelled likewise giving rise to a risk of collision;
c. objects outside the direction being travelled (placed there intentionally or unintentionally), supplying information about the direction, or about the presence of other objects, including the provision of infomation about the speed of the user's own or other vehicles.

Objects in 2 a. and 2 b. are known as risk-bearing; those in 2 c. information-bearing. This sub-division cannot of course always be sharply made.

So far, the discussion has been of a general nature. To decide whether low-beam headlights or side lights are preferable in built-up areas, a more specific approach is necessary, based on the interactions that may occur in city traffic. These can be reduced in general to two basic patterns:
A. Road user A (motorist) does not perceive in time an unlighted object (stationary car, stone, etc., or perhaps a pedestrian, cyclist with no lights) present in his course. The per-

ceptibility limit of the object is governed by the contrast in brightness between the object and its immediate background.
B. Road user A (pedestrian or motorist) does not perceive in time Road user B (car or cycle) carrying marker lights *. The limit of perceptibility of B is governed by the intensity of B's lights in guaranteeing sufficient conspicuousness and recognisability, also in surroundings which may include very many disturbing elements.

These two categories relate substantially to 2 a. and 2 b. above. In built-up areas, 1 as above (direction of the road) and 2 c. as above (information-bearing objects) rarely cause serious problems, firstly because speeds are limited and secondly because practically all the streets are lighted. For the main question in this report, 1 and 2 c. will be disregarded. In the other cases—2 a and 2 b.—the glare caused by the lights of other road users (and to a less extent by the street lighting itself) makes the observer's task more difficult.

Glare is a phenomenon with two aspects. Firstly, 'real' or disability glare. In this case visual perception is disturbed or even rendered impossible. The second aspect is discomfort glare. Little is yet known about the discomfort glare that occurs with illumination by car lamps and the phenomena are not of immediate importance to the problem dealt with in this report; it will not therefore be gone into.

The following will discuss in succession the requirements the driver's own vehicle must satisfy as regards perceptibility of objects (taking into account disability glare), and perceptibility of other vehicles carrying marker lights.

2.4. Visibility of objects

2.4.1. Visibility of objects on the road, when side lights or low-beam headlights are used with street lighting, with no glare from oncoming traffic

An object on the road can be seen only when there is enough difference in photometric brightness or luminance between that object and its background. Luminance contrast is usually formulated as:

$$C = \frac{L_o - L_b}{L_b}$$

C being the luminance contrast (may be either positive or negative)
L_o being the luminance of the object and
L_b the luminance of the background (usually the road surface).

The greater the absolute value of C, the greater the object's visibility. With street lighting, $L_o - L_b$, and hence C, will usually be negative. This is called negative contrast. In the case of illumination by motor headlamps the situation is reversed. The vertical front of the objects is brightly lighted and is therefore often brighter than the road surface—depending on the reflection from the object. In the case of illumination with headlamps only, C is usually positive (positive contrast). It follows that where there is illumination by both headlamps and street lighting, the contrast is usually less than if either form of illumination is used separately [9].

*) 'Marker lights' for present purposes are defined as any lighting at the front of motor verhicles for indicating the presence of that vehicle, such as side lights or (in certain conditions) low-beam headlights.

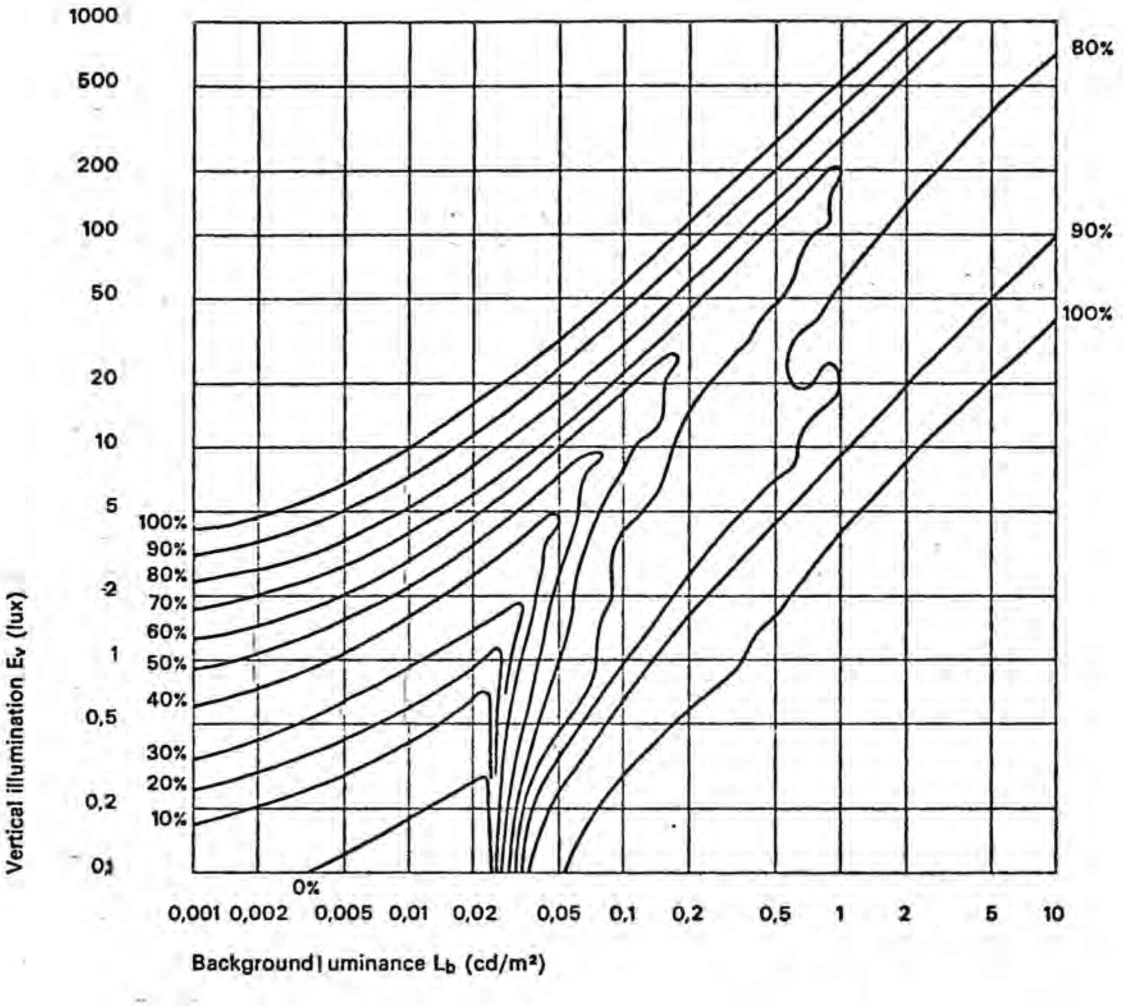


Figure 1. Vertical illumination E_v as a function of background luminance L_b, with 'revealing power' as the parameter.

The influence of low-beam headlights upon contrast where there is street lighting can be determined from Knudsen's [10] considerations concerning 'revealing power'. The method of calculation is briefly as follows:

It has been established by a number of investigations what contrast (as a function of adaptation luminance) is still adequate for road safety. This is called the critical contrast. Next a frequency distribution has been drawn up for the reflection factors of pedestrians' clothing, etc. If the background luminance L_b and the vertical illumination E_v on the plane of the object are given, it can be determined from the frequency distribution what probability there is of the contrast of the object being greater than the critical contrast belonging to L_b. Expressed as a percentage this probability is known as the revealing power. Figure 1 shows illustration No. 7 from Knudsen's paper.

This figure gives the vertical illumination E_v as a function of background luminance L_b, the parameter being the 'revealing power' determined as above.

This figure makes clear what has been said in the last paragraph: good visibility, i.e. high revealing power, is possible only with a very high E_v or else with a low E_v. With an average road-surface luminance of 2 cd/m² corresponding to good road lighting, 100% revealing power either $E_v > 1000$ lux (attainable even with car headlights only from a few metres distance), or $E_v < 8$ lux (attainable with cut-off street lighting lanterns). On the whole, the figure indicates that on roads with a average road-surface luminance greater than about 0.1 cd/m² (i.e. all roads except really badly-lighted ones) the contrasts of objects on the road will not be as great with low-beam headlights as with side lights.
This reduction does not occur:
a. with distances shorter than about 15 metres; owing to the high E_v values there is usually improved detectability of objects;
b. in very dark patches, such as sometimes occur on wet, glossy road surfaces; in this case low-beam headlights may improve visibility, since L_b may be very low.

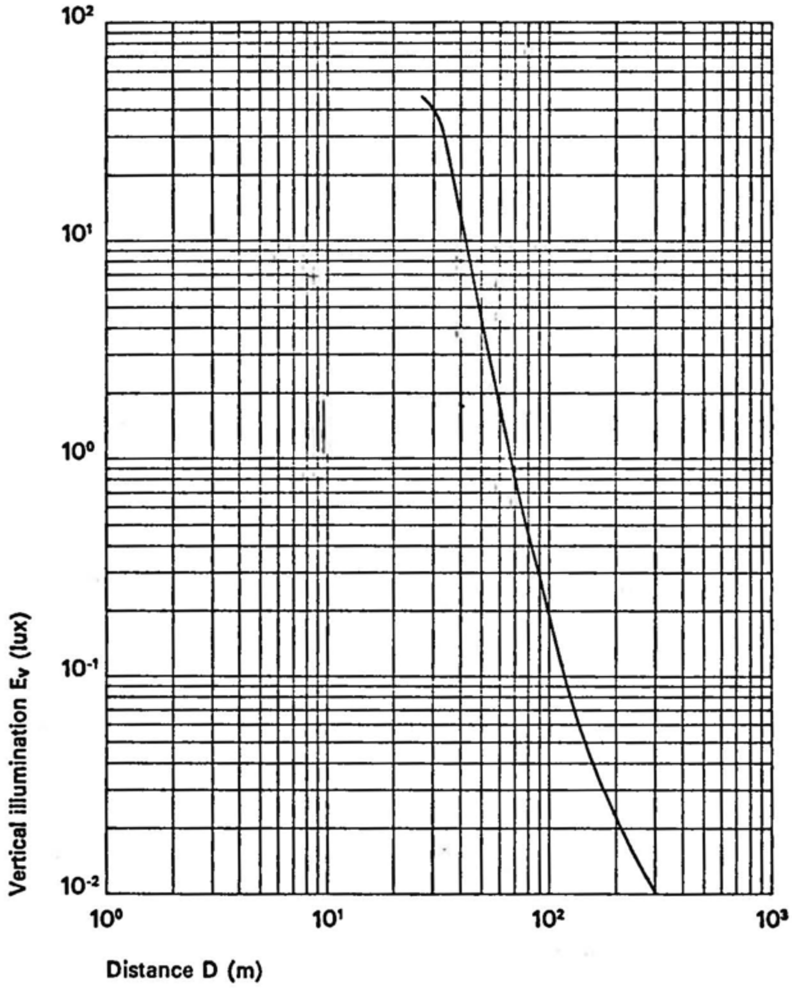


Figure 2. Vertical illumination E_v, as a function of distance D to the vehicle (with two asymmetrical low-beam headlights).

In both cases the improvement in visibility, although sometimes clearly demonstrable, is not usually sufficient to call the situation satisfactory.

In view of the foregoing, it can generally be said that using low-beam headlights does not have much effect on detectability of objects. In fact it is negligible in well-lighted streets. To illustrate this, Figure 2 indicates the vertical illumination immediately in front of two asymmetrical low-beam headlights at road-surface level, as a function of distance (at 30 metres 35 lux and at 50 metres 5 lux). The luminances of dark grey and light grey objects there are then 0.7 and 2.1 cd/m² at 30 metres, and 0.1 and 0.3 cd/m² at 50 m (reflection factors 6% and 18% respectively).
The contribution of low-beam headlights to background luminance L_b is also slight, as is shown by Figure 3 giving the road-surface luminance straight ahead resulting from two, properly adjusted asymmetrical low-beam headlights. The continuous curve applies to a light

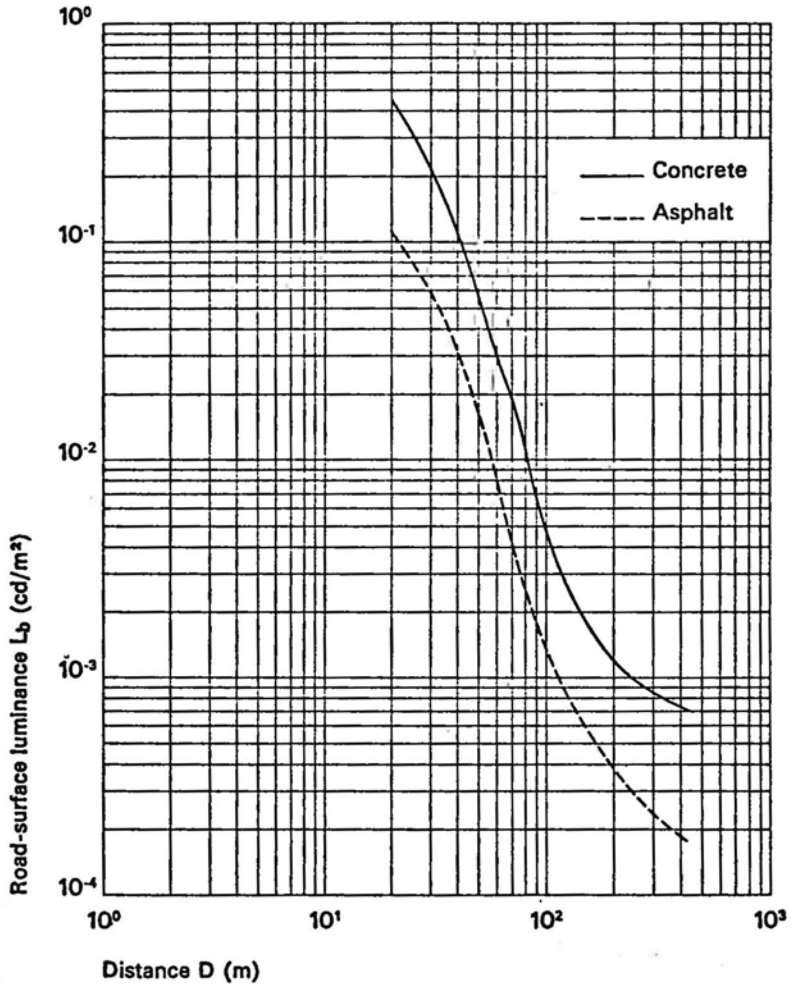


Figure 3. Road-surface luminance L_b, originating from two asymmetrical low-beam headlights, as a function of distance D to the vehicle.

cement concrete road surface (at 30 m: 0.2 cd/m²; at 50 metres: 0.06 cd/m²), the broken curve is for a dark smooth rolled asphalt (at 30 m: 0.06 cd/m²; at 50 m: 0.015 cd/m²).
It clearly follows that the contribution to road-surface luminance at distances over 30 metres, even with moderate street lighting (for instance L_{av} = 1 cd/m²), is negligible. Only in the area immediately in front of the vehicle is there a clearly visible bright patch. But this is a drawback rather than an advantage for detecting objects further away owing to the increase in adaptation level. Moreover, such a bright patch may sometimes create a false feeling of safety, as the driver may wrongly assume that any obstacles will be clearly visible.

Conclusions

In seeking the optimum solution for making objects visible on the road, the quality of the vehicle lighting is negligible in roads or streets with reasonable lighting. Only in the case of installations where the average road-surface luminance is very low or where there are very dark patches, can well adjusted low-beam headlights improve the contrast as compared with side lights. Even then the corresponding perceptibility of objects is usually insufficient and can only be improved by raising the level of street lighting. (These considerations have *not* taken the use of retroflecting materials into account. The perceptibility of objects to which such materials have been applied, can certainly be improved by using low-beam headlights).

2.4.2. The influence of disability glare on visibility of objects in the road

Glare is caused by one or more disturbing bright light sources in the field of vision. It may greatly reduce or obstruct the possibilities of perceptibility.
As already stated, a distinction must be made between:
a. disability glare, and
b. discomfort glare.
The latter is not discussed in this report.

2.4.3. Disability glare

On the whole, Holladay's traditional views on disability glare still apply. Its effect on perceptibility can thereby be described as that of extra veiling of the field of vision. To this veiling an (equivalent) luminance can be attributed. The veil covers both objects and background and the equivalent luminance of both objects (or persons) increases by the same amount. The difference in luminance between object and background, remains therefore the same. The absolute value of the contrast, however, diminishes. For: $C = (L_o - L_b)/L_b$, both L_o and L_b are increased by the equivalent veiling luminance L_s, i.e. in the event of glare the contrast becomes:

$$C' = \frac{(L_o + L_s) - (L_b + L_s)}{L_b + L_s} = \frac{L_o - L_b}{L_b + L_s} \qquad \text{hence: } |C'| < |C|.$$

The equivalent veiling luminance L_s can be calculated from:

$$L_{sj} = \frac{K.E_{oj}}{\theta_j^n}$$

in which:
L_{sj} is the veiling luminance for light source j (cd/m²)
K is a constant
n is a constant
E_{oj} is the vertical illumination caused by the glaring light source j on the surface of the observer's eye (lux),
θ_j is the angle between the directions in which the object and the source of glare j are seen (in degrees).

For $50° > \theta > 1.5°$ Holladay gives:
1. K: depends on the observer's age between 5 and 15 (according to Adrian average $9.2 \approx 10$ [11]).
2. n: about 2
3. L_s: total $= \sum_j L_{sj}$ (additivity)

For $100' > \theta > 10'$, Hartmann and Moser [12] give:
1. K approximately 50
2. n approximately 3.5

For most situations in built-up areas the formula can be used with Holladay's constants, since even 1.5° corresponds to a great longitudinal distance between the vehicles (distal distance R) and a short lateral distance (d). If a range of θ values between about 15° and about 1.5° is considered, Stiles-Holladay applies, but also (a good enough approximation) $\text{tg}\,\theta = \theta$ (θ in radians) because $d \ll R$. Hence θ in degrees:

$$\theta = \frac{180}{\pi} \cdot \frac{d}{R}$$

Furthermore: $E = I/R^2$, I being the intensity of the light-source glare in the observer's direction. Completed, this gives:

$$L_s = \frac{10 \cdot \frac{I}{R^2}}{\frac{180^2}{\pi^2} \cdot \frac{d^2}{R^2}} = \frac{I}{324\, d^2}$$

The veiling luminance L_s is thus proportional to the intensity I and inversely proportional to the square of the lateral distance d, but is unrelated to the distal distance R!. (For very small θ angles Hartmann and Moser's correlation applies; a relationship with both d and R continues to exist).

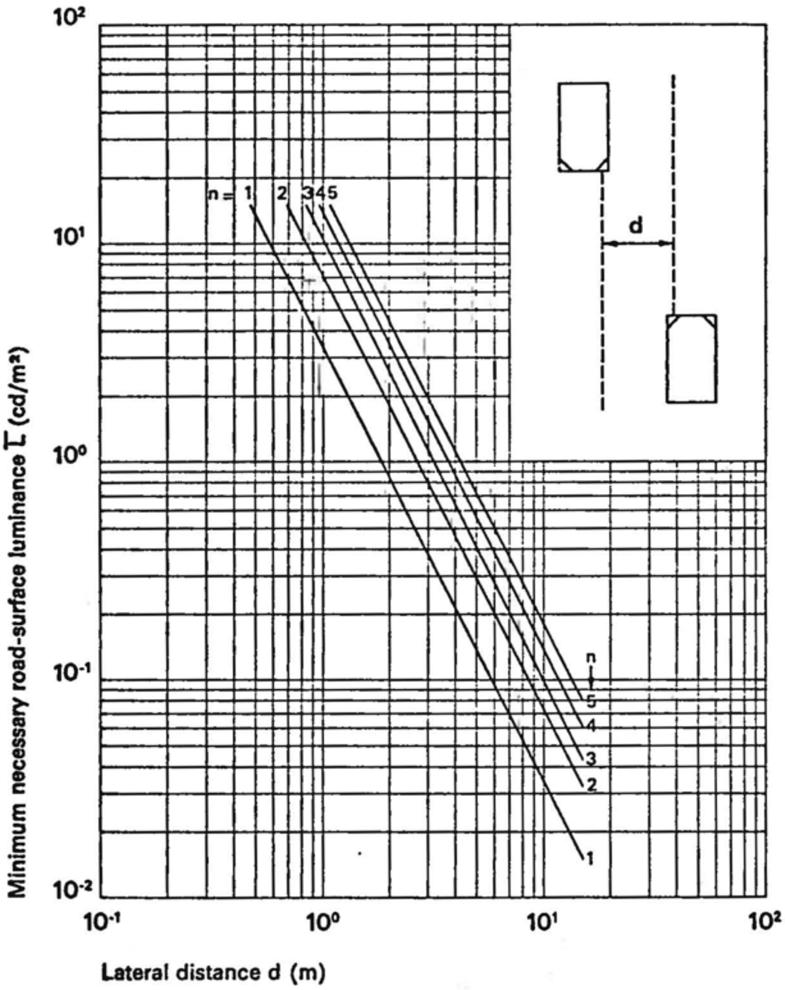


Fig. 4. Minimum necessary road-surface luminance $\bar{L}$ as a function of lateral distance d between a vehicle and n number of approaching vehicles.

Assuming a constant intensity of low-beam headlamps in the relevant region, for every lateral distance (between the observer's eye and the oncoming vehicle's low-beam headlamps) a definite L_s value can be determined. The intensity of a low-beam headlight beam as permitted in Continental Western Europe in directions above the horizontal should not exceed 437.5 cd with the exception that in the direction (3.4 degrees to the left and 0.6 degrees above the horizon) the maximum value is 187.5 cd. In practice, this means that the intensity usually decreases gradually above the horizon. In the following, however, the intensity is considered as constant, because one may expect occasionally intensities that are considerable higher, resulting from poor aiming, etc.
The veiling luminance is then $L_s = 437.5/324\, d^2$.
In view of the additivity of the Stiles-Holladay formula, the total veiling luminance with a large number of oncoming vehicles instead of a single one is easy to determine. In the following, numerical values are used for some of the parameters. To a certain extent, the choice may be regarded as somewhat arbitrary. A discussion follows furtheron. As stated above, an increase in veiling luminance diminishes the contrasts in the field of vision. If the contrast without glare was already close to the threshold value of the observer's contrast sensitivity, it is quite possible for increased veiling luminance to reduce the visible contrast below the threshold value. The object then becomes invisible.

This brings us to a critical point in all considerations on the influence of disability glare: what is the acceptable reduction in perceptible contrast? No generally valid answer can be given. But an increase of 20% in just perceptible contrast can be assumed to have a substantial effect on obstacle perceptibility (i.e. the threshold will increase from say $C = 0.20$ to $C' = 0.24$).
Berek's measurements and calculations (elaborated by Adrian [13]) show that the threshold value of the just perceptible luminance difference ΔL depends on the adaptation luminance L, and approximately according to $\Delta L = 0.1\, L^{0.5}$ for $0.1\ cd/m^2 < L < 10\ cd/m^2$ and for an object of 10 minutes of arc (representative of a small object in the road).
From this the correlation can be determined for the lateral distance d between the two (lines of) cars approaching each other and the essential minimum background luminance (now equalised with average road-surface luminance) so that the contrast sensitivity threshold value does not increase by more than 20%. The number of oncoming vehicles simultaneously perceptible is the parameter. This is shown as a graph in Figure 4, arrived at as follows:
Without glare, $\Delta L = 0.1\, L^{0.5}$. With glare, ΔL increases to $\Delta L'$, and L to $L + L_s$; hence $\Delta L' = 0.1\, (L + L_s)^{0.5}$. The contrast is $\Delta L/L$; hence for these two cases:

$$C = \frac{\Delta L}{L} = 0.1\, L^{-0.5} \text{ and } C' = \frac{\Delta L'}{L + L_s} = 0.1\, (L + L_s)^{-0.5}$$

$$\text{Therefore } \frac{C}{C'} = \frac{\Delta L}{L} \Big/ \frac{\Delta L'}{L + L_s} = \left(\frac{L}{L + L_s}\right)^{-0.5} = \left(\frac{L + L_s}{L}\right)^{0.5}$$

Let us now call the relative change in contrast

$$\frac{C - C'}{C'} = p, \text{ hence } \frac{C}{C'} - 1 = p. \quad \text{Therefore } \frac{C}{C'} = 1 + p.$$

$$\text{Then } 1 + p = \left(\frac{L + L_s}{L}\right)^{0.5}; \text{ hence } (1 + p)^2 = \frac{L + L_s}{L} = 1 + \frac{L_s}{L}$$

If $p < 1$, then $p^2 \ll p$; therefore $(1 + p)^2 = (1 + 2p + p^2) \approx 1 + 2p$.
Then $1 + 2p = 1 + (L_s/L)$ and $p = L_s/2L$. Let us assume for calculating Figure 4 that $p = 0.2$ and $L_s = I/324d^2$, with $I = 437.5$ cd per vehicle.

For n oncoming vehicles, therefore, $L_s = n \times 437.5/324d^2$, and lastly

$$0.2 = \frac{n \times 437.5}{324d^2} \cdot \frac{1}{2L} \text{ or } L = \frac{3.38n}{d^2}$$

This formula is illustrated in Figure 4 (see page 22).
The lateral distance d is plotted on the horizontal axis. It is assumed that only the left-hand lamp of each is visible (right-hand traffic). The vertical axis gives the minimum background luminance, where glare remains below the given limit.
The graph shows, for instance, that on narrow two-lane roads (with no central reservation), when $d \approx 1.5$ m, a background luminance of about 1.5 cd/m² is needed for one (half) oncoming vehicle, but five successive oncoming vehicles, for instance, require 7 cd/m².
Here, it should be mentioned that d = 1.5 m is not much for the moment of passing. In narrow city-streets with bicycles, parked cars etc., however, the course usually is not perfectly straight, resulting in practical values of $d \approx 0$ when the opposing vehicles are still at some distance from each other.
If we take dual carriage-way roads with separation and with a minimum lateral distance of about 4 m, we find that (half) an oncoming vehicle requires a minimum background luminance of 0.2 cd/m², while five require about 1.0 cd/m². This shows the great influence of the number of oncoming vehicles visible at the same time; theories so far, which have allowed for only one oncoming vehicle, give incorrect results for present-day urban traffic.
In this way it can also be found what headlamp intensity is still tolerable for lighted streets without separated lanes ($d \approx 1.5$ m). With an increase in threshold value of p = 20% and an average road-surface luminance resulting from street-lighting of 1.0 cd/m², the admissible intensity of headlamps is about 60 cd for five oncoming vehicles (n = 5).
The minimum values of the road surface luminance given here are depending on the numerical values used for the parameters. Values in the center of the practical region are aimed at. Thus, the equivalent veiling luminance is strongly dependent on age ($5 < K < 15$). Furthermore, L_s is supposed to be independent of R. This keeps the middel between the results of Hartmann and Moser [12] with decreasing L_s at decreasing R, and the results of De Boer and Vermeulen [22] where visibility decreases with decreasing R. The choice of I = constant has been discussed already. The exponent of L in the formula used $\Delta L = 0.1\ L^{0.5}$ depends on the surrounding luminance and on the size of the object. Furthermore, the time of exposition is important. Blackwell [23] indicates an exponent of about 0.6 for the relevant region. De Boer [24] quotes considerably higher values. Taking into account the far higher threshold values found by De Boer, it seems justified to presume that differences in experimental set-up may have played an important rôle. A higher value of the experiment leads to less glare; opposed to this the glare-increasing result of rain, wet road surfaces and wet or dirty wind-screens may be mentioned.
It is not always possible to indicate numerically how the glare depends on the variations in the parameters as indicated. As practice indicates, many occasions arise when glare gives rise to an unacceptable reduction in visibility. An acceptable situation will be found when all factors are more favourable than the average. This leads to the following conclusions.

Conclusions:

Even the present internationally standardised asymmetrical European low-beam headlight causes an unacceptable degree of glare for oncoming traffic, unless there are only a few oncoming vehicles of the average road-surface luminance is much greater than at present customary, or unless the central reservation for dual carriage-way roads is very wide. No such conditions are customary in built-up areas, and present low-beam headlights are therefore inadmissible in built-up areas because of the glare they cause.

Note: The newly developed duplo-halogen lamps cast about the same light at oncoming traffic. As regards glare, therefore, they hardly differ from conventional lamps, also having regard to the little they contribute to road-surface luminance.

2.5. Perceptibility of lighted vehicles

2.5.1. Visibility

A lighted vehicle may be visible (for definition see 2.2.) in two ways; one does not preclude the other.
Firstly, the vehicle itself may be visible. The reasoning of 2.4. relating to visibility of objects can be applied unchanged, since a vehicle is also an object. The need for well-lighted streets has already pointed out.
The second means by which a vehicle can be seen is by the visibility of its lights. But since the requirements regarding conspicuousness of vehicle lighting, discussed below, are much stricter than for visibility, there is no need to go into the visibility of marker lighted vehicles.

2.5.2. Conspicuousness

Conspicuousness is conditional, but not only so, upon visibility. (For definitions of visibility, conspicuousness, etc. see 2.2.). The existence in road and traffic conditions of other elements demanding the driver's attention may mean that an object is in fact first perceived at a distance much shorter than the visibility distance. In some cases an object, itself visible, may not be perceived at all. Investigations have shown, for instance, that a signalling light is much less perceptible if observed among other lights of about the same intensity. This is even more so if the intensity of the distracting lights is much greater than that of the light in question. For instance, a car with side light is much less conspicuous if there are cars with low-beam or high-beam headlights near by. Visibility can, of course, also be reduced by disability glare. Lastly, the conspicuousness of light signals is found to be greatly reduced if there are many of them. (For instance a blue flashing light is much more conspicuous than the common yellow light, even though the yellow light has greater visibility).
Conspicuousness is influenced by expectations based on past experience. It can be compared with the fact that a pedestrian crossing a motorway outside a built-up area will often be observed much later than a pedestrian on a zebra crossing in town, even though the pedestrian may be just as visible in both cases.

Conclusions

Conspicuousness of vehicle lighting plays a primary part in the problem of side lights or low-beam headlights in built-up areas, particularly in regard to the advisability of uniform lighting.

2.5.3. Recognisability

The main contribution lighting makes towards recognisability of vehicles, is the possibility of distinguishing various categories of vehicles. On the whole different categories can be indicated with different lights, or by the difference in number and/or positioning of lights. For instance, the position of lights will reveal the difference between a big lorry and a private car. In some cases, however, this does not guarantee proper recognisition in time. It is very important, for instance, to be able to see the difference in good time between a motor cycle, a moped, and a car with a defective headlamp. The colour of the light could be used as an indication. Recognition of the different categories of vehicles, however, is still inadequate. Distinguishing features include observation of the differences, for instance, between moving and stationary cars. A stationary car on the road is not recognisable as such from general features: as whether or not its rear lights are burning for instance. For unmistakable recognition in such a situation (i.e. that the car is stationary), specific indications must be uniformly applied. Alternating direction indicators, flashing brake lights and warning triangles are now available for such situations.
A uniform indication is also specifically advisable for cars parked in well-lighted streets. One possibility is to use no lights when stationary and to use side lights or low-beam headlights when moving.
Such specific indications unmistakably show that the car is not moving but is stationary. The latter is, of course, only possible with very well lighted streets.

Conclusions

Recognisability of various categories of road users and whether vehicles are stationary or not is very important in this question of side lights or dimmed headlights.

2.5.4. Defining position

For road safety it is very important to be able to define and recognise precisely the position of objects and their characteristic movements. Determination of position and movement consists of three processes:

1. Assessing distance to objects.
2. Assessing speed of objects.
3. Assessing differences between driver's own speed and the speed of objects.

In practice, 2 and 3 will usually coincide as a matter of detecting and assessing relative speeds.

Assessment of distances is a familiar matter. For distances beyond a few metres, optical convergence and parallax no longer play a part. The dimensions of the object must be known. In road traffic after dark usually only the lights of vehicles are visible, and assessment would be improved if the lights of all vehicles of the same category had the same distance between them. It is not feasible to assess distances from the apparent brightness of lights. Assessment of relative speed involves firstly the change per unit of time in the angle from which the driver perceives the object. See Figure 5. As the distance q between the driver and the object decreases, there is an increase in the angle α at which the object is perceived.
The change in angle $\Delta\alpha/\Delta t$ occurring per unit of time has a more or less linear relationship with the relative speed. The boundary value of $\Delta\alpha/\Delta t$, is often taken as 2 or 3 minutes of arc per second at normal day and dusk illumination levels and also for street lighting [14].
For lighted vehicles the distance q is determined by the distance between the light sources, i.e. at the front by distances between headlamps or side lights, and at the rear by the distance between rear lights. For accurate determination of relative speeds, therefore, there ought to be a uniform distance between these light sources. Another, and probably more accurate assess-

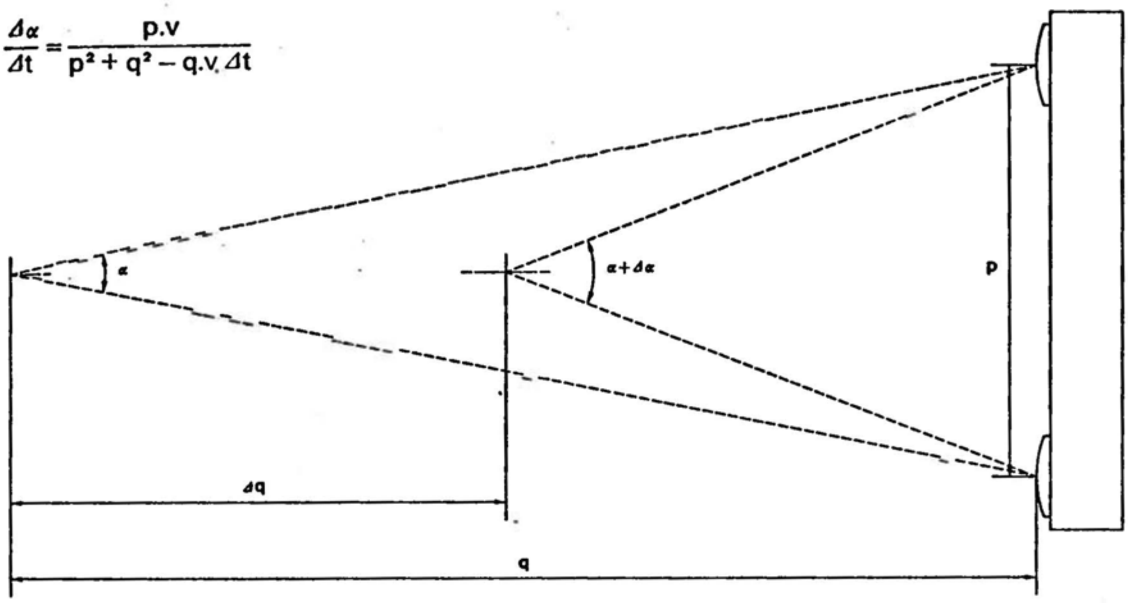


Figure 5. Detection of difference in speed by estimating change in vehicle's apparent size.

ment of distance and relative speed is possible by road users if the object is clearly outlined against its background, for instance the road surface, or nearby trees, etc. After dark, of course, such an assessment is possible only with good street lighting. Besides the means of lighting themselves, the contours of the road are very important because they may function as a reference system. In many cases, it is important to know the time available before the moving vehicle reaches a particular point. This means that distance and speed are implied in assessing the time available, but need not be determined separately. This situation presents itself in overtaking, and when pedestrians cross the road.

Conclusions

To determine the location and (relative) movement of objects, both the configuration of a car's lights and lighting of the surroundings are important. The relative importance of these two aspects and the way they occur in combination must be examined separately, however, The commencement of such investigations is described in Section 4.

2.6. Need for research

In the foregoing analysis of the problem, extensive (often implicit) use has been made of published research results. This applies particularly to the data on visual characteristics, such as contrast sensitivity, glare sensitivity, threshold values for visibility and movement detection, etc.
Since this research is generally known, and many of the results have already been given in the foregoing, detailed discussion of the experiments is not at present required. Additional research is needed for some aspects.

Important results of statistical research have also been published in the past. They concern mainly the 'dipped headlights campaign' in Britain in 1963 and 1964. Although this campaign produced few definite results, it is of sufficient importance to go into it in greater detail, especially as literature on it is not always readily accessible [1, 15].
In the United Kingdom, fairly extensive statistical research was carried out in several large towns, as 'before' and 'after' studies, to ascertain the effect of changing from side lights to low-beam headlights on the pattern of accidents. On the whole this research yielded no definite results, inter alia because:
1. The number of road users that responded to the request to drive with low-beam headlights in the cities in question was fairly small (e.g. Birmingham 60%, Worcester 25%).
2. The percentage of low-beam headlight drivers also increased in the 'control' cities, (not included in the campaign) and the data from these towns are therefore not so valuable for statistical verification.
3. In both campaign and control cities, street lighting was widely improved during the campaign.
4. Many incidental campaigns were conducted, including stricter speed limit enforcement, special publicity, one-way traffic in some main streets, and so on.

Although these investigations permit no general conclusions regarding the question of side lights or low-beam headlights in built-up areas', some interesting tendencies were noted:
1. The number of accidents after dark involving pedestrians decreased when low-beam headlights were used.
2. The number of other accidents (i.e. not involving pedestrians) decreased in poorly-lighted streets, but increased slightly in well-lighted streets.

On the whole, this statistical investigation, in conjunction with other investigations, permits the following conclusions to be drawn:
1. The accident risk is greater at night than in daytime.
2. The accident risk after dark is greatly influenced by:
a. street-lighting standards,
b. car-lighting standards.

As regards 2 a. and 2 b. the following:
European cities have greatly improved their street lighting, especially in recent years, and the Netherlands has certainly kept pace.
The quality of side lights has also greatly improved in recent years. European cars built before 1960 often had side lights with intensities even less than 1 cd. This applied especially to cars with side lamps not fixed in the headlamp itself but behind the reflector.
Since about 1961 the intensity of most cars' side lights has been greatly increased. Side lights below 5 cd now hardly ever occur; 15 to 25 cd is no longer exceptional.
The Economic Commission for Europe on 16th January 1967 proposed the introduction of a minimum of 4 cd for side lights [16].

Since the answer to the 'side lights or low-beam headlights in built-up areas' question is influenced so much by these two factors, i.e. street-lighting and car-lighting standards, combined with the fact that these factors have recently changed so greatly, it is possible that in a country where low-beam headlights were demonstrably better some years ago it is now advisable to use side lights owing to improved street and vehicle lighting.

Conclusions

The experimental research must be supplemented because it is not yet known how, by assessing speed and distance, an observer assesses the time available before a moving vehicle reaches a given point (See 2.5.3.).
Statistical research as carried out in the UK needs enlarging upon because the available material is already rather out-dated, it relates mainly to specifically British conditions and the influence of side-effects upon the tests renders the significance of the results too slight as basis for recommending any official action.

3. Statistical research

3.1. Purpose

As stated in the preceding Section (see 2.1.), the object of the statistical research is to ascertain whether there is a correlation between a given type of vehicle lighting and accident rate in built-up areas.
This creates a number of limitations and conditions, but at the same time raises a number of new questions. The limitations and conditions are:
1. The research relates only to road safety in built-up areas. As regards vehicle lighting, therefore, only the influence of side lights or low-beam headlights will be investigated. (Vehicle lighting where side lights remain burning when low-beam headlights are switched on is regarded as low-beam headlights).
2. The criterion for testing the influence of vehicle lighting on road safety is expressed as the number of accidents. The visibility standards for vehicle lighting formulated by illuminating engineers are therefore inadequate in this sense as a criterion of what is good or bad.

It is advisable to illustrate this very important condition. A road accident is a consequence of the highly complex interaction of a large number of factors, of which visibility is only one. Compliance with all visibility standards may not therefore always lead to optimum road safety. Similarly, *non-optimum* visibility (for instance excessive glare) may be amply offset by other factors and unexpectedly lead to fewer accidents. The road user's subjective assessment of the risks plays a large part in this.

Some of the questions which the objects give rise to are:
a. Is it advisable to have one type of lighting, or does using side lights and low-beam headlights indiscriminately have little effect?
b. Does street lighting at a particular location have any influence on the use of side lights or low-beam headlights?
c. Does present vehicle lighting satisfy all requirements for maximum road safety?

The statistical research described in this Section is limited to answering questions a. and b. Question c. was partly covered by experimental research. The results are discussed in Section 4.

3.2. Procedure

The basic procedure was:
1. Ascertain the usage of side lights and low-beam headlights in a built-up area.
2. Bring about the greatest possible change in this usage for a given period.
3. Examine what effect this change has had on road safety (number of accidents) in the built-up area.

Although the principle is simple a number of conditions must be satisfied in working out the details. These, and the way they have been met are elucidated below.

3.2.1. Campaign period

The research was carried out from December 1964 to February 1965. A drawback was that the campaign was liable to be affected by snow, ice, fog, etc. Sub-section 3.2.2. indicates how this was allowed for.

3.2.2. Campaign and control cities

Besides side lights and low-beam headlights, there are other factors affecting road safely during investigations. Some of these can be controlled fairly precisely: official regulations, road improvements, etc. Others cannot be foreseen but may affect the occurrence of road accidents. Weather is one example (See 3.2.1.).
Because of these considerations it is therefore necessary to include one or more control cities in the before and after study.

The choice of such cities was more or less limited because the following had to be taken into account:
1. The number of expected accidents had to be big enough (at least about 5000 a year, including 5% to 10% involving motor vehicles after dark in the period from December to February), in order not to limit the scope of analysis upon division into different kinds of accidents.
2. The proportion of side-light drivers in the campaign city had to be 70% to 80% in order to be sure that the maximum effect would be obtained upon switching over to low -beam headlights; at least one of the control cities would have to be comparable.
3. As regards suitable cities it had to be certain that the authorities had no plans for measures immediately before or during the campaign which might greatly influence road safety.
4. At least one of the control cities would have to be close enough to the campaign city for the same weather (snow, rain and frost) to be expected.

All this ultimately led to Utrecht being chosen for the campaign and Amsterdam, The Hague and Groningen being chosen as controls. Table 1 shows these cities' principal traffic and other characteristics.

1965	Utrecht	Amsterdam	Den Haag	Groningen
Population (1.1.1965)	267.001	866.290	598.709	152.513
Area in hectares (1.1.66)	5.152	15.641	6.486	2.741
Built-up area in hectares	3.009	8.154	4.349	2.094
Population per hectare built up	89	106	138	73
Length of metalled roads in km	472	1.165	1.090	205
Ditto in built-up area*	398	1.040	1.090	194
Number of motor vehicles	40.602	144.742	100.418	21.471
Number of private cars	30.098	115.853	78.197	16.354
Percentage private cars/motor vehicles	74%	80%	78%	76%
Number of road accidents	10.358	31.868	24.428	4.271
Number involving injuries (or fatal)	2.027	5.163	3.196	604
Number of metres metalled road in built-up area per motor vehicle	10	7	11	9
Number of accidents involving injuries per km metalled road in built-up area	5	5	3	3
Percentage of side-light drivers before campaign	64%	79%	83%	17%

* roads with 50 km or 70 km per hr. speed limit

Table 1. Data on campaign city (Utrecht) and controls (Amsterdam, The Hague, Groningen) (1965).

3.2.3. Use of side lights and low-beam headlights

In order to assess the use of side lights and low- beam headlights, counts were taken in all the cities. A pilot study was first made to examine whether it was in fact possible to distinguish between side lights and/or low-beam headlights. Tests in which two observers independently counted vehicles with side lights or low-beam headlights proved reliable observation to be possible (for description of this study see Appendix I, page 61).
Next, a count programme was drawn up for the campaign. Since the count could not be more than a sample, it was necessary to know what influence various factors had on driving with side lights and low-beam headlights.
Counts were thus made in one week, on all days of the week, and in various types of street in Utrecht. The results of this pilot study showed that driving with side lights or low-beam headlights was in fact related to factors such as the day of the week, the level of street lighting and the type of street. (Further information on this pilot study is given in Appendix II, page 62).
The count programme (See Table 2) for the campaign period includes therefore every day of the week three times. Moreover, two types of street were taken on each day, divided into well-lighted and poorly-lighted streets. Table 3 lists the streets in which the counts were taken.

All the counts were taken between 7.30 p.m. and 8.30 p.m. The choice of this hour was governed by the following practical aspects.
1. The counts had to take place after dark.
2. Counting during the evening rush proved impracticable.
3. The late evening hours were likewise unsuitable as there was too little traffic and too few observations.

In analysing the data it was taken for granted that the time of evening or night has no effect on the use of side lights or low-beam headlights.
The streets were chosen in consultation with the local police officers and illuminating engineers.
The primary idea of dividing street lighting into five luminance levels had to be abandoned because it was not possible to obtain uniform criteria. In most cases no data were obtainable and the campaign time too short to make subsequent luminance measurements in all the streets where accidents had occurred.
For streets where the counts were made, therefore, street lighting was simply divided into 'good' and 'poor'. Although this sub-division is subjective, there is sufficient evidence that it reasonably indicates the level of lighting. This was checked with illuminating engineers in Utrecht and the control cities by asking their opinions on the 'goodness' or 'poorness' of a number of lighting installations. Table 4 gives the data for the 'campaign streets'.

As road surface conditions (wet or dry) could not be foreseen, these were not taken into account in drawing up the count programme. Surface conditions were recorded during the count and their influence was subsequently examined.

	1964						1965								
Sunday	15/11	22/11	29/11	6/12	**13/12**	20/12	27/12	3/1	**10/1**	17/1	24/1	31/1	7/2	**14/2**	21/2
Monday	16/11	23/11	30/11	**7/12**	14/12	21/12	**28/12**	4/1	11/1	18/1	**25/1**	1/2	8/2	15/2	22/2
Tuesday	17/11	24/11	1/12	8/12	15/12	**22/12**	29/12	5/1	12/1	19/1	26/1	**2/2**	9/2	16/2	**23/2**
Wednesday	18/11	25/11	2/12	9/12	**16/12**	23/12	30/12	6/1	13/1	**20/1**	27/1	3/2	10/2	**17/2**	24/2
Thursday	**19/11**	26/11	**3/12**	10/12	17/12	24/12	31/12	7/1	**14/1**	21/1	28/1	4/2	**11/2**	18/2	25/2
Friday	20/11	**27/11**	4/12	11/12	18/12	25/12	1/1	**8/1**	15/1	22/1	29/1	**5/2**	12/2	19/2	26/2
Saturday	21/11	28/11	5/12	**12/12**	19/12	26/12	**2/1**	9/1	16/1	23/1	**30/1**	6/2	13/2	20/2	27/2

Table 2. Counting programme. Days when counts were taken are been printed bold.

	Main roads into town		Distributing roads	
	'good' street lighting	'poor' street lighting	'good' street lighting	'poor' street lighting
Utrecht	1. Gr. v. Roggenweg	2. Amsterdamse straatweg	3. Nobelstraat	4. P. Nieuwlandstraat
Amsterdam	5. Haarlemmerweg	6. Middenweg	7. v. Baerlestraat	8. Churchilllaan
The Hague	9. Middachtenweg	10. Oude Waalsdorperweg	11. Weteringkade	12. Kamperfoeliestraat
Groningen	13. Hereweg	14. Damsterdiep	15. Ged. Zuiderdiep	16. Zaagmuldersweg

Table 3. Streets were counts were taken.

City and street (See Table 3)		Illumination in lux (average)	Type of lighting	Roadway width in m	Road metalling
Utrecht	1	15 lux	sodium	2x9	bitumen
	2	8 lux	sodium	8–10.5	brick setts
	3	12 lux	tube	±9	bitumen
	4	8 lux	mercury	±9	brick setts
Amsterdam	5	11 lux	sodium	9	bitumen
	6	5 lux	incandescent	11–15	bitumen
	7	8 lux	mercury	18	bitumen
	8	11 lux	sodium	2x9	bitumen
Den Haag	9	10 lux	mercury	2x7	bitumen
	10	5 lux	mixed	9–12	brick setts
	11	12 lux	mercury	2x8.5	bitumen
	12	5 lux	mercury	10	bitumen
Groningen	13	35 lux	mercury	13	bitumen
	14	20 lux	sodium	9	bitumen
	15	32 lux	mercury	13	bitumen
	16	4 lux	incandescent	7.5–10	bitumen

Table 4. Campaign street data.

Note: The assessment of 'good' or 'poor' lighting is based on subjective impressions. Consequently good lighting may not always correspond to high intensity.

3.2.4. Influencing behaviour

In order to persuade motorists to drive in Utrecht as much as possible with low-beam headlights, a local publicity campaign was conducted. This was not, of course, allowed to have any effect on behaviour in the control cities.
The campaign was as follows (See also Figure 6):
1. Boards were placed on all main roads entering Utrecht, asking motorists to use low-beam headlights.
2. A direct mail letter signed by the Chief Superintendent of Police was distributed to all Utrecht car-owners asking them to assist in the campaign.
3. A press conference, to which only the local press were invited, was arranged to explain the purpose and procedure of the campaign. Several press releases were also issued in the course of the campaign.
4. During the campaign 25,000 pamphlets were distributed via fleet owners and garages and at car parks and petrol stations, likewise calling for co-operation.

3.2.5. Accident recording

In order to ascertain whether the change in driving behaviour did in fact influence road safety, it was necessary to extend normal accident recording by adding the following additional information:
1. The lights carried by the vehicles involved in an accident: no lights, side lights, low-beam headlights or high-beam headlights.
2. The level of street-lighting at the site of the accident, sub-divided into three classes.
3. The make, type and year of the vehicles involved in the accident.

The intention of the first item is clear. It was to determine the influence on accident involvement of driving with, say, low-beam headlights.
The street-lighting data were needed to assess any interaction between driving or accident involvement and on the one hand a particular kind of lighting and on the other a particular level of street-lighting.
The vehicle information made it possible to ascertain the make and type of headlamp of the vehicle in question.
For practical reasons the police in the cities concerned were unable to supply the required information. Recording the information in 2 and 3 caused very great problems, and due to this incompleteness this information made practically no contribution to the analysis (See 3.3.1.). An endeavour was made to supply the missing information, but without success.

3.3. Results

3.3.1. General

The following problems limited the analysis.
1. It is not known for Amsterdam, and only partly known for Utrecht, what kind of lights were carried by motor vehicles involved in road accidents after dark (See Tables 9a, b and c, page 47).
For these two cities it was hardly possible, if at all, to ascertain whether there was any correlation between driving with a given kind of light and accident involvement.
2. In at least two of the four cities the number of accidents after dark involving pedestrians was too small for any reliable conclusions to be drawn. There was thus no definite confirmation of the conclusions of the UK, campaign [17] that the number of accidents involving pedestrians decreases with low-beam headlights instead of side lights.
3. Since it was impossible (See 3.2.3.) to obtain reliable information about lighting levels of

Figure 6. Folders and posters used for low-beam headlights compaign in Utrecht.

all streets where accidents had occurred, it could not be investigated whether, besides vehicle lighting, the accident rate was also influenced by street lighting.

These imperfections in the available figures reduced the chances of finding certain correlations.

3.3.2. Influence of the low-beam headlight campaign on road users' behaviour

3.3.2.1. Driving with side lights or low-beam headlights

Figure 7 gives in graph form the percentage of low-beam headlight drivers counted during the period. It shows, inter alia, that driving with side lights is comparatively common in Amsterdam and The Hague.
The influence of the low-beam headlight campaign (See 3.2.4.) is clear from the Utrecht figures. Before it, about 37% of Utrecht car drivers and motor cyclists used low-beam headlights. In the first few weeks of the campaign this increased to 75%. For the remainder of the campaign it was about 80%.
The graph also shows clearly that the Utrecht campaign had *no* influence upon the use of low-beam headlights in the control cities.
Counts, one month and also one year after the end of the campaign, however, showed that the use of low-beam headlights declined again in Utrecht. One month after, the rate was about 60%, and a year later about 55%. The pre-campaign rate (37%) has not however been reached, and the campaign has apparently had some permanent effect.

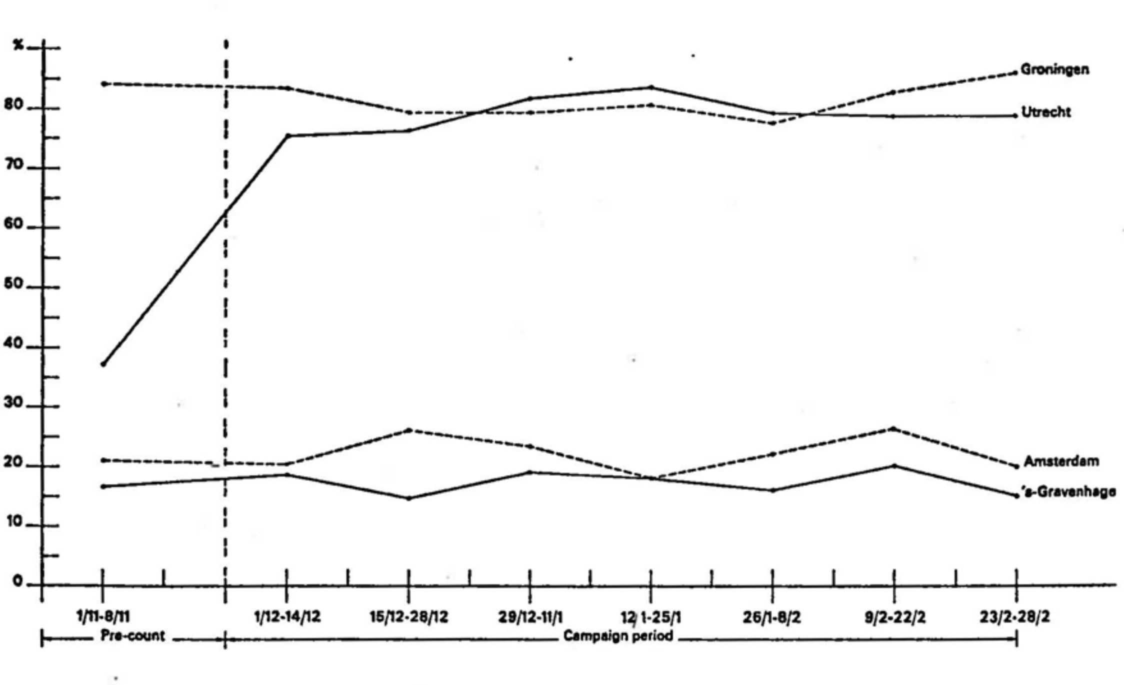


Fig. 7. Percentages of low-beam headlight drivers in Utrecht and control cities before and during campaign.

Number of count days	A1				A2			
	B1		B2		B1		B2	
	C1	C2	C1	C2	C1	C2	C1	C2
1	73.5	83.3	82.7	85.8	61.3	58.3	74.6	85.5
2	79.9	85.9	87.2	89.5	75.5	74.7	84.6	88.4
3	87.7	81.0	89.2	88.0	67.1	61.9	82.4	84.8
4	85.5	81.6	82.5	86.9	72.2	76.5	87.2	91.4
5	82.2	90.8	91.1	90.6	61.1	65.0	86.0	84.9
6	77.4	78.8	86.7	87.1	89.0	68.9	87.4	83.0
7	84.4	86.7	88.3	80.1	84.8	88.7	85.8	85.9
8	79.1	90.2	85.3	93.1	76.6	74.0	84.0	89.0
9	83.0		90.0		68.5		82.3	
10	83.2		86.1		70.1		84.7	
11	81.8		91.6		67.0		84.3	
12	85.1		87.1		82.6		88.1	
13	78.8		89.4		73.2		88.1	
14	79.2		91.5		71.4		85.0	
Σx_{ij}	1140.8	678.3	1228.7	701.1	1010.4	568.0	1184.5	692.9
Σx_{ij}^2	93142.14	57644.27	107949.89	61545.89	73708.22	40978.74	100370.41	60066.63
Total Σx_{ij} 7,204.7 Total Σx_{ij}^2 595,406.14								

Table 5. Percentage of low-beam headlight drivers in Utrecht subdivided for type of road (A1: Main roads into town; A2: Distribution roads), quality of lighting (B1: good; B2: poor) and road surface conditions (1: dry; C2: wet).

3.3.2.2. Factors influencing behaviour

By making counts in two different kinds of street—'well-lighted' and 'poorly-lighted'—the influence of these factors on driving with side lights and low-beam headlights was examined. Moreover, out of the 22 days' counting in Utrecht, there were 8 on which the road surface was wetted by rain. The influence of this factor was therefore also examined. The figures of this analysis are given in Table 5.
They show the percentage of low-beam headlight drivers during the entire period of observation (1 hour) on a given day in the city of Utrecht, divided into two types of street, good or poor street-lighting and wet or dry road surface.

In order to determine the influence of the three factors and their interactions a variance analysis was made (A statistical justification of this is given in Appendix III, page 64).
This analysis shows that the factors: type of street (A1 and A2) and lighting standards (B1 and B2) do indeed clearly influence driving with side lights or low-beam headlights. There is also some interaction between the two factors.
These results are summarised in Table 6. This gives the averages for the classes and the percentages of low-beam headlight drivers.
It can be interpreted as follows (See also Figures 8 and 9).
1. In poorly-lighted streets low-beam headlights are used more than in well-lighted streets.
2. On main roads entering town low-beam headlights are used more than on distributing roads.
3. Owing to interaction effects low-beam headlights are always used more than average on well-lighted main roads entering town. These conclusions apply not only to Utrecht but also to the control cities (See Figures 10 and 11) and a general conclusion is therefore reasonable.

	B1	B2	Average
A1	82,7%	87,7%	85,2%
A2	71,8%	85,3%	78,5%
average	77,2%	86,5%	81,9%

Table 6. Category averages for percentages of low-beam headlight drivers in Utrecht subdivided for type of road (A1: Main roads into town; A2: Distribution roads) and quality of lighting (B1: good; B2: poor).

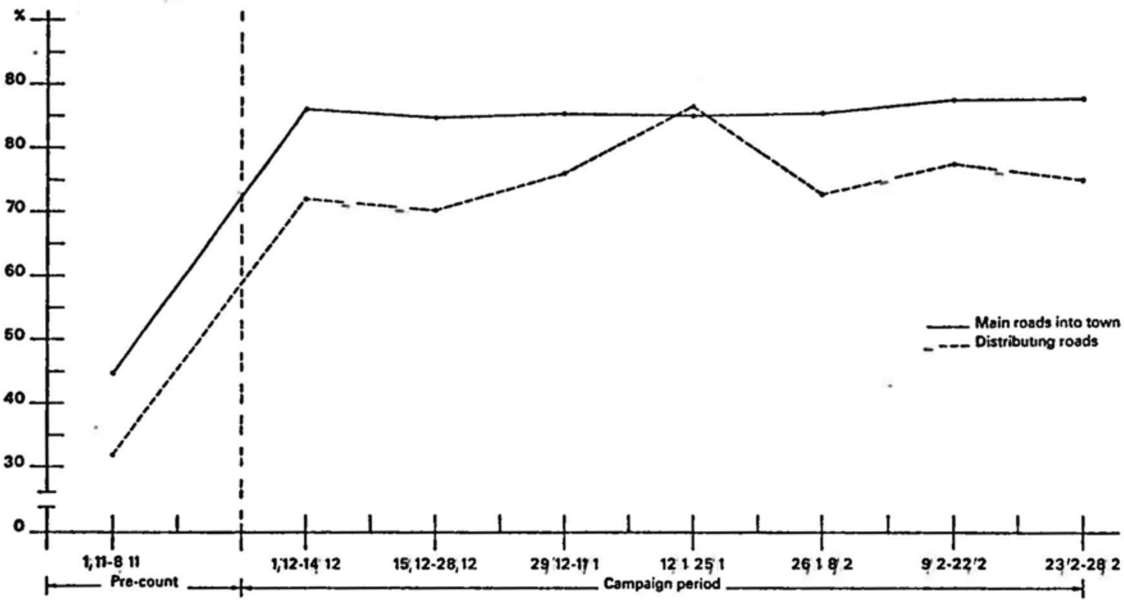


Figure 8. Percentages of low- beam headlight drivers in Utrecht in various types of street.

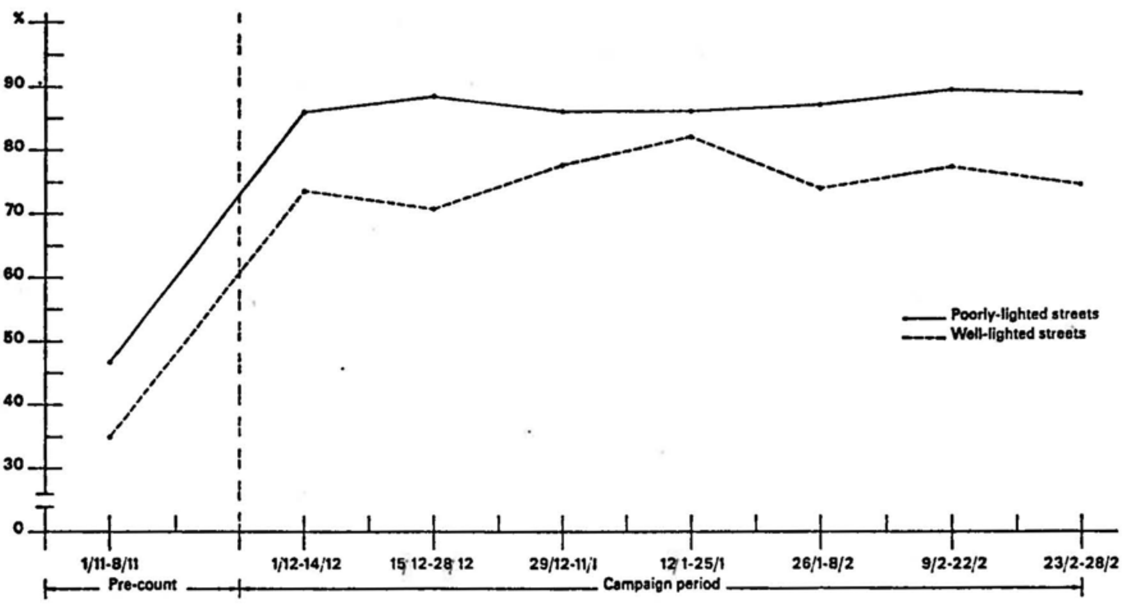


Figure 9. Percentages of low-beam headlight drivers in Utrecht with various qualities of street lighting.

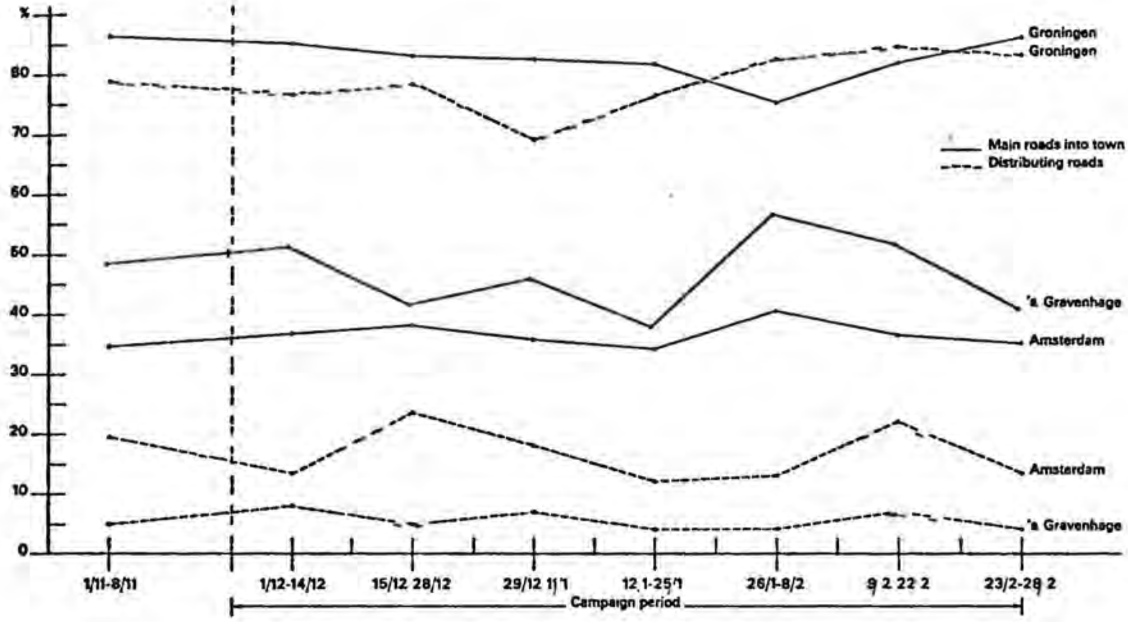


Figure 10. Percentages of low-beam headlight drivers in control cities in various types of street.

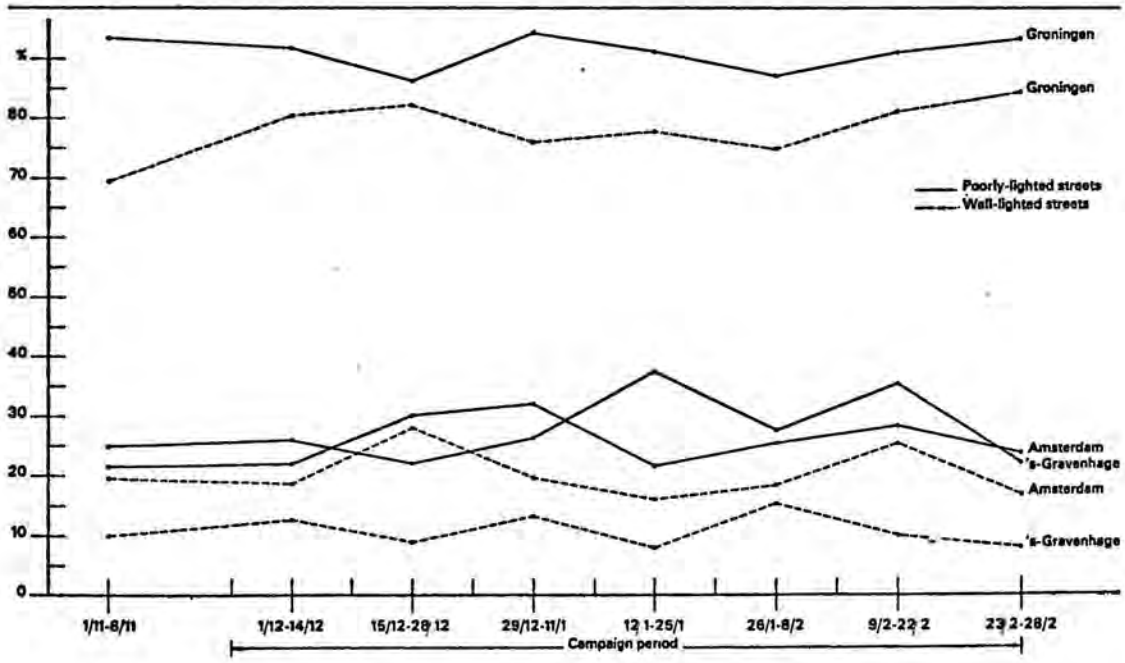


Figure 11. Percentages of low-beam headlight drivers in control cities with various qualities of street lighting.

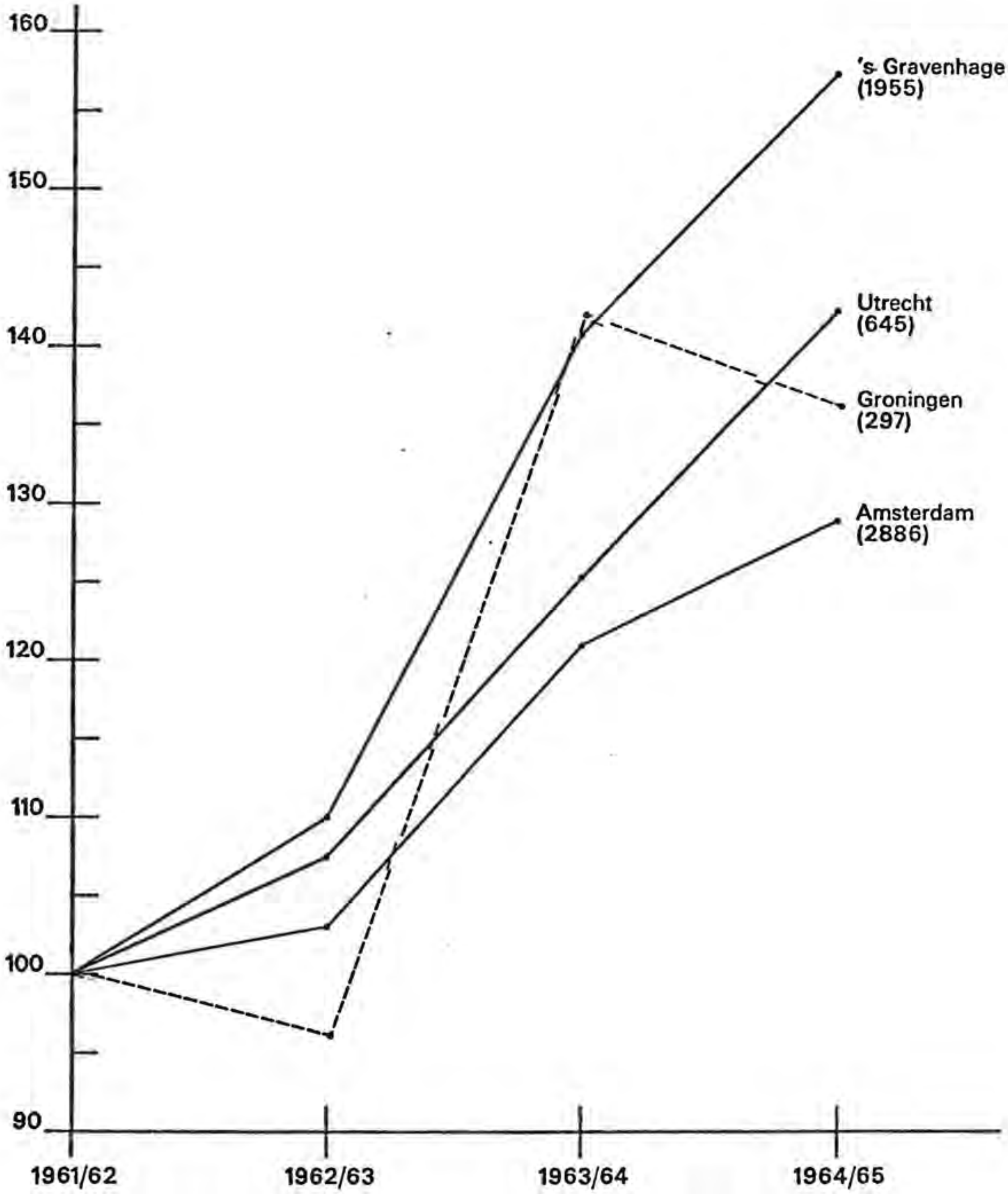


Figure 12. Trend in number of accidents with motor vehicles after dark (1961/62 = 100) from December to February.

Note: The absolute figures for all night-time accidents in 1964/1965 are stated in brackets.

3.3.3. Influence on accidents of change in behaviour

3.3.3.1. Motor-vehicle accidents

The major part of the investigations was the determination of the effect of increased use of low-beam headlights on road safety in Utrecht. Accidents not involving motor vehicles were disregarded. It was also assumed that the use of side lights or low-beam headlights had no direct effect on the occurrence of accidents involving only mopeds, cyclists and pedestrians, etc. Moreover, only accidents were analysed that occurred after dark in the built-up area. Figure 12 compares such accidents recorded in Utrecht during the campaign (December 1964 to February 1965) with those in the same period in preceding years. It also shows the trend of the same types of accident in the three control cities.

There is obviously no question of a favourable effect on the total extent of road safely in Utrecht. The number of accidents after dark involving motor vehicles increased almost in line with previous years' trends. Nor do the figures for the control cities disclose any special trend in Utrecht although, compared with the period 1963/1964, night-time accidents in Utrecht increased relatively more than in the control cities. The Groningen figures are somewhat more erratic. This may be because the number of accidents in Groningen is comparatively small (1964/1965: 877; 297 of these involving motor vehicles after dark).
Chance effects alone may cause much greater scatter in the comparable monthly totals. For instance, the weather: in Groningen out of the 22 count days in December 1964 to February 1965, there were 12 with rain or sleet, compared with 8 in Utrecht.
Allowing for the growth of traffic in Utrecht, no improvement was apparent in the relative safely. Table 7 gives figures prompting this conclusion. The density index in this table relates solely to growth of traffic in the Utrecht city area. Counts around the city area indicate that traffic there is growing more rapidly. The given density indexes are therefore probably rather low for the Utrecht urban area as a whole.

Nevertheless the relative safety trend (i.e. the accident index related to density index) is not such that 1964/1965 stands out as a safer period. In fact no absolute conclusions are justified, owing to the defective nature of the observations relating to densities.

	Density in index figures	Accidents in index figures	Accidents/Density in index figures
1961/1962	100	100	100
1962/1963	106	107	101
1963/1964	120	125	104
1964/1965	127	141	111

Table 7. Trend in number of accidents involving motor vehicles related to growth in traffic density in (centre of) Utrecht.

3.3.3.2. Day-time/night-time ratios

Figure 13 shows the trend in the accident rate after dark. An attempt has been made with this to determine whether the trend in the number of accidents after dark differs from the number in day-time. However, the data show no relative decrease during the campaign period in the number of accidents after dark. The slight increase from about 33% to 35% has no statistical significance. It is a chance effect (of unforeseeable factors, such as the weather). For instance, the general decrease in all cities in the months of December 1962 to February 1963 is obviously due to the severe winter. This greatly distorted the ratio between day-time and night-time accidents in all cities. It may be caused by a decrease in the number of day-time

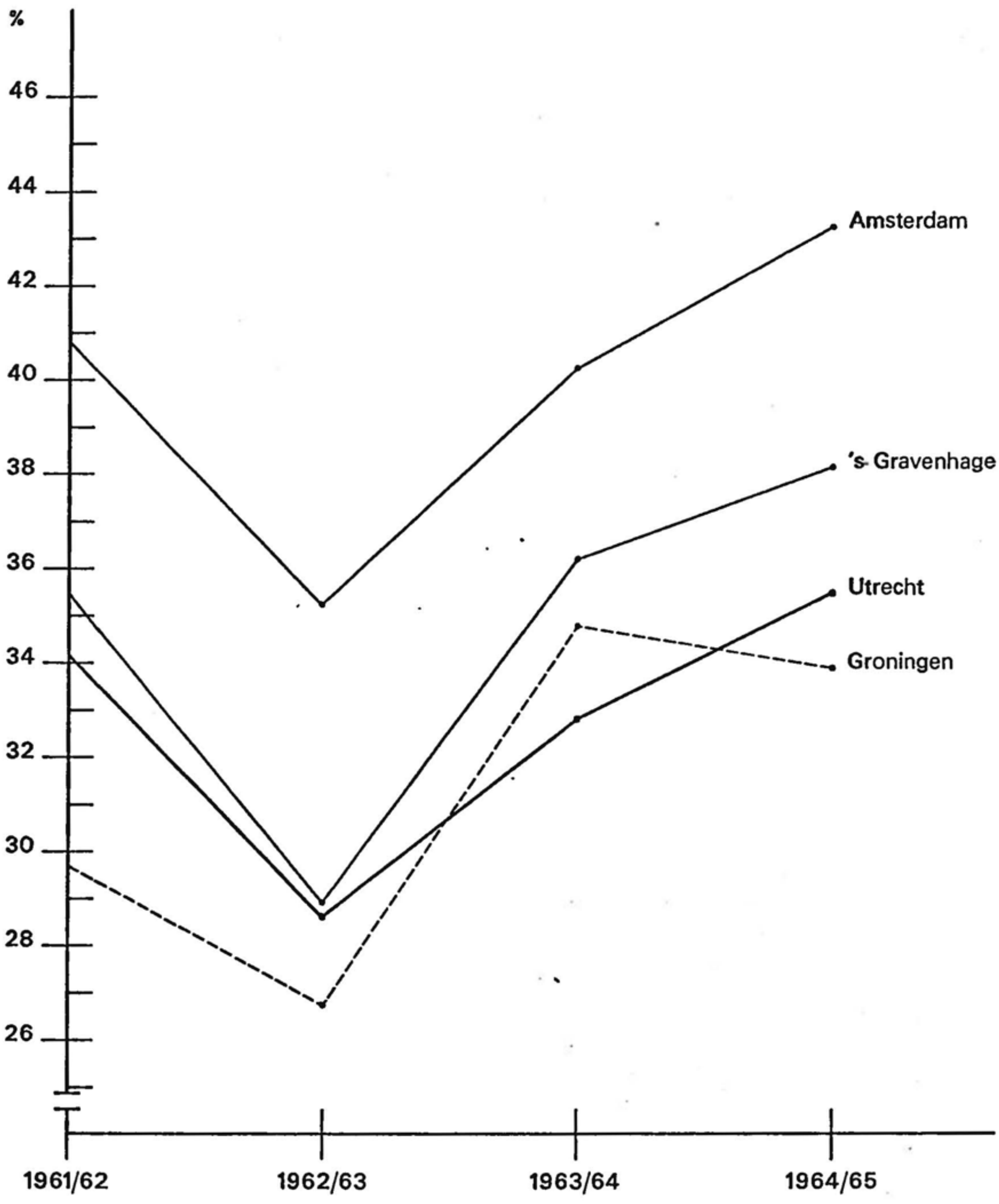


Figure 13. Trend in percentage of accidents with motor vehicles after dark compared with number of day-time accidents with motor vehicles, in December to February.

accidents or to an increase in the number of night-time accidents. This will not be gone into further at present.

The same applies in fact to the day-time/night-time ratio in Utrecht in 1964/1965. A possible decrease in after-dark accidents may have been compensated for by a decrease in day-time accidents, leaving the quotient unchanged. In conjunction with 3.3.3.1., however the conclusion is that there is sufficient certainty that the Utrecht low-beam headlight campaign had no direct, demonstrable influence on over-all night-time traffic safety in the city. It is still possible, however, that there was some limited influence on certain kinds of accident as was revealed, inter alia, by UK research [2] and [17].

3.3.3.3. Accidents involving pedestrians

The British campaign referred to above suggests that using 'dipped' headlights *) favourably affected the number of road accidents involving motorcars and pedestrians. Table 8 lists the number of accidents involving pedestrians in all cities covered by the investigations. Furthermore, accidents to pedestrians are calculated as a percentage of all accidents in the period concerned.
Further examination of these figures give rise to the following remarks. The number of motor vehicle/pedestrian accidents in Utrecht (and in Groningen) was too small in the campaign period and earlier years to warrant any conclusions regarding the campaign's influence on the occurrence of such accidents. Nor has the favourable trend in the day-time/night-time ratio any statistical significance.
It is striking that all cities, apart from Amsterdam, showed a declining trend in pedestrian accidents, also as percentages of the total. A possible explanation is the relative amount of pedestrian traffic in the cities. The percentage increase in Amsterdam, however, is not so easy to explain. (SWOV is meanwhile collecting information for research into accidents involving pedestrians).

The question whether the British findings regarding low-beam headlights and accidents to pedestrians also apply for Dutch conditions cannot therefore be answered from this information. The reason why a potential influence on pedestrian accidents was bound to be more striking in the British campaign may be that the percentage represented by pedestrian accidents among all accidents involving injury is much greater in Britain than in the Netherlands [18].
Furthermore, criteria for recording road accidents are different in the Netherlands and Britain. It is therefore quite possible for the influence, if any, on pedestrian accidents in Britain to be more readily measurable. For instance, the criterion for recording an accident in Britain is: 'the occurrence of injury'. In the Netherlands, however, accidents to pedestrians with minor injuries may not be recorded because there are no grounds for prosecution. The definition of an 'accident involving a pedestrian' is also capable of different interpretations. If a pedestrian has caused an accident (for instance on or near a pedestrian crossing) but is not himself the victim, this is not treated in the Netherlands as a pedestrian accident.
In 3.3.4., accidents involving pedestrians will be gone into further, but only as regards involvement in accidents with low-beam headlight drivers.

*) It should be pointed out that the British system of car lighting differs greatly from the Continental European system.

	1961/1962		1962/1963		1963/1964		1964/1965	
	number	percentage of all accidents	number	percentage of all accidents	number	percentage of all accidents	number	percentage of all accidents
UTRECHT								
day-light	13	1.5	19	1.5	4	0.3	3	0.3
night-time	10	2.2	7	1.4	3	0.5	1	0.16
GRONINGEN								
day-light	11	2.2	11	1.9	9	1.6	3	0.5
night-time	8	3.7	5	2.4	3	1.0	1	0.3
DEN HAAG								
day-light	66	3.0	55	1.7	17	0.6	12	0.4
night-time	38	3.1	30	2.2	9	0.5	11	0.6
AMSTERDAM								
day-light	107	3.4	72	1.7	104	2.6	127	3.5
night-time	71	3.2	51	2.2	57	2.1	71	2.5

Table 8. Accidents involving motor vehicles and pedestrians, December to February.

3.3.4. Use of low-beam headlights related to accident involvement

In addition to before and after study of accident figures for Utrecht, the relationship between using side lights or low-beam headlights and involvement in road accidents was also investigated as follows. The starting point was the hypothesis that the risk of being involved in an accident must be the same for all motorists driving with low-beam headlights as the proportion of such drivers in road traffice as a whole.

$$P_{lb\ (accident)} = \frac{\text{all low-beam headlight drivers}}{\text{all motorists after dark}}$$

If observations therefore show that the proportion of low-beam headlight drivers involved in accident differs from the proportion they represent in road traffic as a whole, this hypothesis warrants the conclusion that there is a correlation between the kind of car lighting and accident involvement.

UTRECHT	M_n	M_p	L_n	L_p	S_n	S_p	G_n	G_p
Collision type I								
Collision type II								
Collision type III								
Total	996	100%	606	61%	62	6%	328	33%

GRONINGEN	M_n	M_p	L_n	L_p	S_n	S_p	G_n	G_p
Collision type I	328	100%	171	52%	98	30%	59	18%
Collision type II	58	100%	31	53%	11	19%	16	28%
Collision type III	5	100%	3	60%	—	—	2	40%
Total	391	100%	205	52%	109	28%	77	20%

DEN HAAG	M_n	M_p	L_n	L_p	S_n	S_p	G_n	G_p
Collision type I	2378	100%	187	8%	2179	92%	12	—
Collision type II	375	100%	26	7%	339	91%	10	2%
Collision type III	54	100%	1	2%	42	78%	11	20%
Total	2807	100%	214	8%	2560	91%	33	1%

Table 9a, b, c. Motor vehicles (M) involved in accidents, according to numbers (n) and percentages (p), and sub-division into type of collision (I = motor vehicle and motor vehicle; II = motor vehicle and slow traffic; III = motor vehicle and pedestrian) and type of light (L = low-beam headlights; S = side lights, G = none). Note: These data are not available for Amsterdam.

Tables 9a, b and c give, for Utrecht, Groningen and The Hague, the numbers and percentages of motor verhicles involved in accidents in the campaign period. Owing to a number of practical problems in recording road accidents in Utrecht (see also 3.2.5.) the number of motor vehicles whose lighting was not known is fairly great. (It is fair to assume that a comparatively high percentage had side lights). Consequently, the recorded number of low-beam headlight drivers involved in accidents has a relatively large margin of error. As regards

Utrecht, therefore, the following conclusions must be interpreted with the necessary circumspection.
Table 10 compares the above-mentioned low-beam headlight percentages with the average percentages arrived at from traffic counts (See 3.3.2.1.). Comparison with pre-campaign figures was not possible because no additional data regarding the use of side lights or low-beam headlights were recorded for accidents before the campaign.

The figures show that in all three cities the percentage of low-beam headlight drivers involved in accidents is much lower than would be expected from the proportion of such drivers in traffic as a whole (See Appendix IV, page 66). The conclusion is that a correlation must exist between driving with low- beam headlights and less frequent accident involvement.
This conclusion is in fact strengthened by the following argument. Based on behaviour observations (See 3.3.2.2.), it has been found that driving with low- beam headlights is influenced by street-lighting quality and by type of street. Poor street lighting on the one hand leads to more frequent use of low-beam headlights, but on the other the accident rate is greater owing to the low general degree of visibility [5]. Based on this therefore, it may be argued that low-beam headlight drivers are more likely to be involved in accidents. Not because of the low-beam headlights, but because of other conditions that have also led to low- beam headlights being used.

The foregoing has shown, however, that the number of low-beam headlight drivers actually involved in accidents is much lower than would be expected from a proportional distribution. A greater accident rate owing to the interaction between low-beam headlights and poorly-lighted streets strengthens this effect.
The question remains however why there is apparently a relationship on the one hand between low-beam headlights and fewer accidents, while on the other hand a sudden increase in the number of low-beam headlight users (in Utrecht) had no noticeable effect on the total number of accidents involving motor vehicles.
The explanation might be that as the percentage of low-beam headlight drivers increases and hence the percentage of side light drivers decreases, there is a smaller accident risk for low-beam headlight drivers but a greater one for side light drivers. This becomes progressively greater as the percentage of side light drivers is reduced.
Another explanation, which does not necessarily preclude the foregoing argument but perhaps supplements it, is that the sudden change from about 35% low-beam headlight drivers to about 80% may have altered the traffic pattern after dark so radically that there was some need to get acclimatised to it. This might have adversely affected the pattern of accidents. This is indicated by the fact that the percentage of low-beam headlight drivers involved in accidents in the first six weeks of the campaign was higher, i.e. 68%, than in the last seven weeks when it was 53% (See Figure 14). For the whole campaign period it was 61% (See Table 10), subject to the inaccuracy of the observation material already mentioned.
The figures for Groningen also point in this direction. As regards the percentage of low-beam headlight drivers, this city was comparable with Utrecht (82% compared with 79%). In Groningen, where the high percentage of low-beam headlight drivers was not reached owing to a sudden change, the percentage of these drivers involved in accidents is much lower (average 52%). During the entire campaign this remained fairly constant (See also Figure 14).
A factor that probably plays an important part in the above hypotheses is the degree of uniformity in type of car lighting. The mixture of side lights and low-beam headlights and also the luminance of the car's lamps play a part. Traffic conditions in which there are many cars with low-beam headlights while there are few with side lights, inconspicuous as they are anyway, may well create a situation which is not as safe as when side light drivers are in the vast majority. Only complete uniformity (100% low-beam headlight drivers) will improve this. Accident statistics, however, have not yet furnished enough evidence on this point.
To be able to give a more concrete opinion about this, more comprehensive accident statistics are needed, differentiated to show kind and type of car lighting and related to data on the use of side lights and low-beam headlights.
There are clear indications that the conspicuousness of car lighting is a major factor. This is

reflected by motor vehicle/pedestrian accidents in The Hague during the campaign period. There were 54 accidents after dark in The Hague involving motor vehicles and pedestrians. Of these 54, however, only one involved a car with low-beam headlight (See Table 8c). This is only 2% of all accidents involving pedestrians, whereas in The Hague the proportion of low-beam headlight drivers is about 17% (See table 10). The proportion of low-beam headlight drivers in accidents with other road users (non-pedestrians) is much greater by comparison. There were too few accidents involving pedestrians in Groningen and Utrecht to say with any certainty whether the number of accidents involving low-beam headlight drivers was comparatively small.
In any case, the figures for The Hague confirm the positive influence, found in the British campaign, of easily visible car lighting, especially in the motor car/pedestrian interaction.

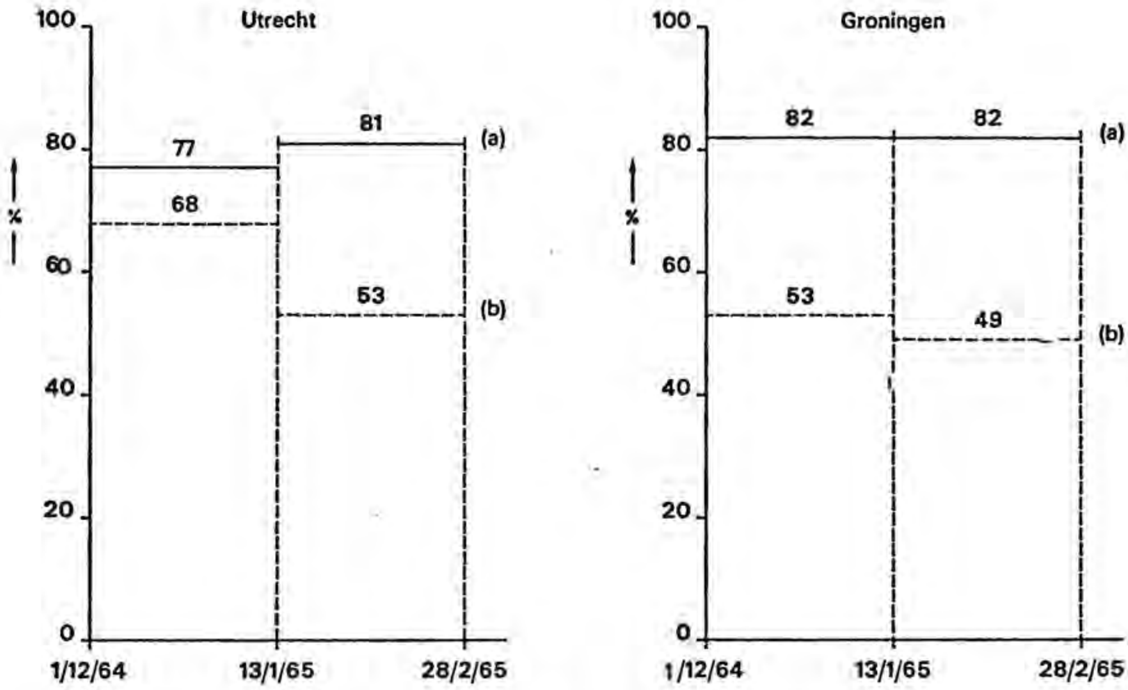


Figure 14. Low-beam headlight drivers as a percentage of all motorists (a) compared with the percentage of low-beam headlight drivers involved in accidents (b) in the campaign period in Utrecht and the percentage for Groningen, a control city.

	Proportion of low-beam headlight drivers involved in accidents	Proportion of low-beam headlight drivers in traffic
Utrecht	61%	79%
Groningen	52%	82%
Den Haag	8%	17%

Table 10. Proportion of low-beam headlight drivers involved in accidents and proportion of low- beam headlight drivers in traffic.

3.4. Conclusions

The statistical research confirmed a number of hypotheses, and some interesting conclusions were possible even though the analysis of accident data was made difficult by limitations in recording and by the small number of accidents. The conclusions are:

1. Driving with side lights or low-beam headlights in built- up areas is influenced by level of street-lighting and type of street, respectively the traffic pattern.
There is a definite tendency during relatively poor visibility to offset this by using low-beam headlights.

2. The increase in low-beam headlight driving from about 35% to 80% in the built-up area of Utrecht had no demonstrable influence on road safety. Nor was the accident ratio after dark (i.e. the day-time/night-time ratio) significantly changed.
There are indications that as the percentage of low-beam headlight drivers increases, there is less accident risk for these drivers and a greater risk for side light drivers.
The effect of using low-beam headlights may also be lessened by an accustoming or acclimatisation process owing to the sudden change in traffic patterns. The lack of uniformity in car lighting may well have played a part in this (See also point 3).

3. In the control cities Groningen and The Hague, and to a less extent in Utrecht it was found that the risk of accident involvement for low-beam headlight drivers is less than would be expected from their proportion in road traffic.
The degree of uniformity in car lighting probably plays some part in this. If there is a mixture of many low-beam headlights and few side lights, then side lights are very inconspicuous, for instance. Moreover, the intensity, especially of side lights, is greatly spread. It can therefore be concluded that side lights and low-beam headlights ought not to be in use at the same time. It can also be concluded that the closest possible uniformity should be aimed at, not only in construction of car lights but also in the use of side lights or low-beam headlights.

4. In one of the cities, the number of accidents involving motor vehicles with low-beam headlights and pedestrians in particular was smaller than would be expected from the percentage of low-beam headlight drivers in that city. This in fact confirms the supposition that the average visibility of present side lights is inadequate under certain conditions.

4. Experimental research

4.1. Object and procedure

4.1.1. Introduction

Some of the night-time road accidents involving road-crossing pedestrians and motor vehicles are attributed to the pedestrian having wrongly judged the distance and/or speed of the approaching motor vehicle at the time of crossing the road.
This section describes a number of experiments carried out to ascertain whether and, if so, to what extent pedestrians' decisions to cross the road or not depend on the intensity of the motor vehicle's lights and the level of streetlighting.
These experiments were motivated as follows. With a given car speed, a fixed road width, a definite walking speed and a constant or negligible time for the pedestrian's decision, a specific car-to-pedestrian distance can be indicated corresponding to the 'safe-to-cross' limit. If the car is further away, the pedestrian can most certainly cross safely; if it is closer to, it is no longer safe to cross.
If the conditions are given, this distance corresponds to a definite time the pedestrian needs to decide and to cross (t). The experiments examined what proportion of pedestrians believe they can cross, depending upon the time taken to cross. If no errors were made, the proportion

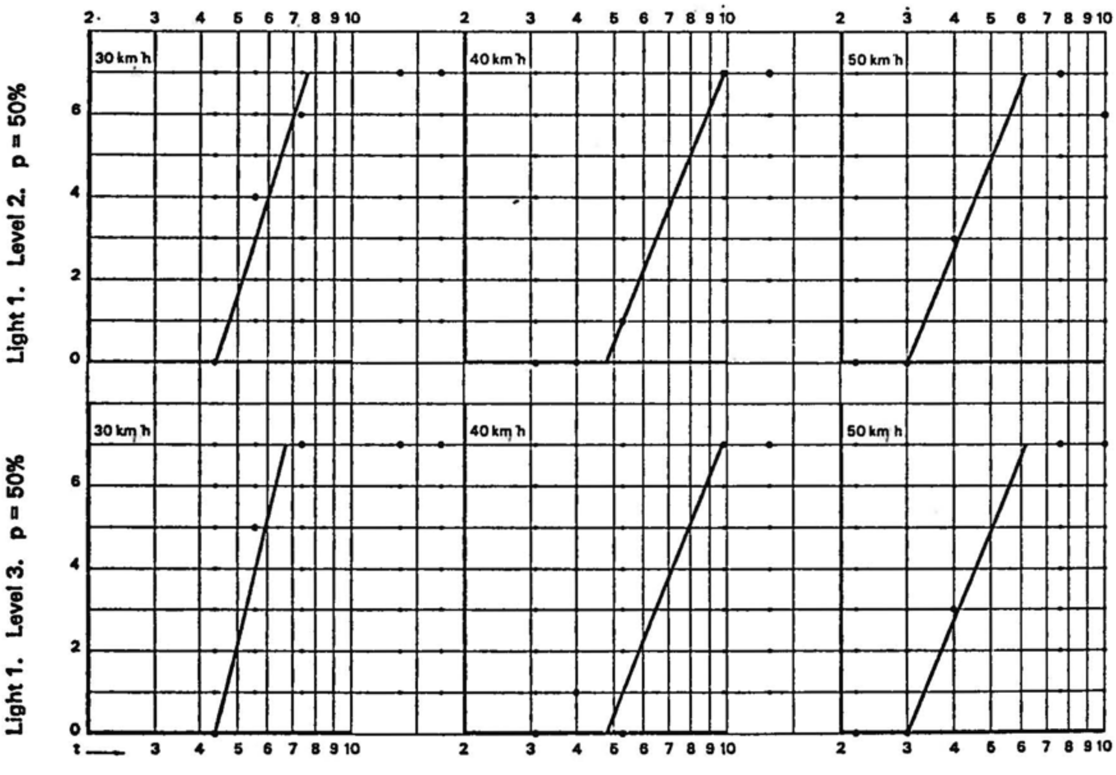


Figure 15

would be 0% when $t < t_v$ (t_v being the least safe crossing-time) and 100% when $t > t_v$. The actual p-t diagram is not rectangular, because wrong decisions are made.
There are two types of wrong decisions. The first (undoubtedly more serious) is that the pedestrian wrongly thinks he can cross when he cannot ($t < t_v$). The second type of wrong decision is not to cross ($t > t_v$).
Errors of the former type may affect road safety and are thus very important for present purposes. Those of the latter type may reduce the capacity of the road and pedestrian crossings and/or interfere with the smooth flow of traffic. Type I and II errors can be shown in a p-t diagram (See Figure 15).
For road safety, area I should be small, if possible non-existent; if area II is small smooth traffic flow and road capacity are aided. Direct experimental determination of areas I and II is not possible because a generally valid t_v value cannot be determined under actual conditions. The t_v factor is introduced only to clarify the relevant processes. Moreover, for the problems dealt with in this report, absolute determination of t_v is unimportant; what is required is the extent to which pedestrians' behaviour depends on extraneous circumstances. Hence the characteristic values for the p-t diagram chosen below are: the t value at which p = 50%, and the inclination at that point. The effect, if any, of car lighting intensity on the frequency of wrong decisions by pedestrians may be refected in two ways: the t value at which p = 50% and also the inclination may depend on the light intensity. The former means that the estimate of available time (i.e. the estimate of distance or of speed, or both) depends on this intensity. It is also possible that the decision time depends on this. The latter means that uncertainty in these estimates depends on the intensity, i.e. the frequency of wrong decisions depends on this.

The experiments were made as follows: A car drove towards a number of stationary observers— in an observation cabin provided with small shutters. The intensity of the car lights and the speed were different each time. The street-lighting level was also varied. The shutters were opened briefly when the car reached a certain distance from the observers. This distance also differed each time. As quickly as possible after the shutters were opened the observers indicated whether they would cross the road or not under these conditions. The decisions and decision times were recorded. If there are enough observers the correlation between p and t can be determined for any combination of intensity/street lighting/driving speed.

The experiments were made at the Lighting Laboratory of N.V. Philips' Gloeilampenfabrieken, Eindhoven, with the collaboration of the Institute for Perception RVO-TNO, Soesterberg, the Ministry of Transport and Waterways and the Utrecht Police.

4.1.2. The vehicle

A white DAF-600 private car was used. It was fitted with four lamps at both right and left (Figure 16). The relative intensity distribution of all the lamps was the same (Figure 17). The intensity maximum was fixed at four definite values: 0.3–3–30 and 300 cd by the choice of lamps and, if necessary, by adjustment with variable resistors. The lowest of these values corresponds to a very weak sidelight and the highest to about the intenisty of a well-adjusted low-beam headlight facing an oncoming driver. The intensity distribution was such that the light patch on the road in front of the car was much weaker than that of a normal low-beam headlight. The four lights all had practically the same colour.
Three speeds were used: 30, 40 and 50 km/h.

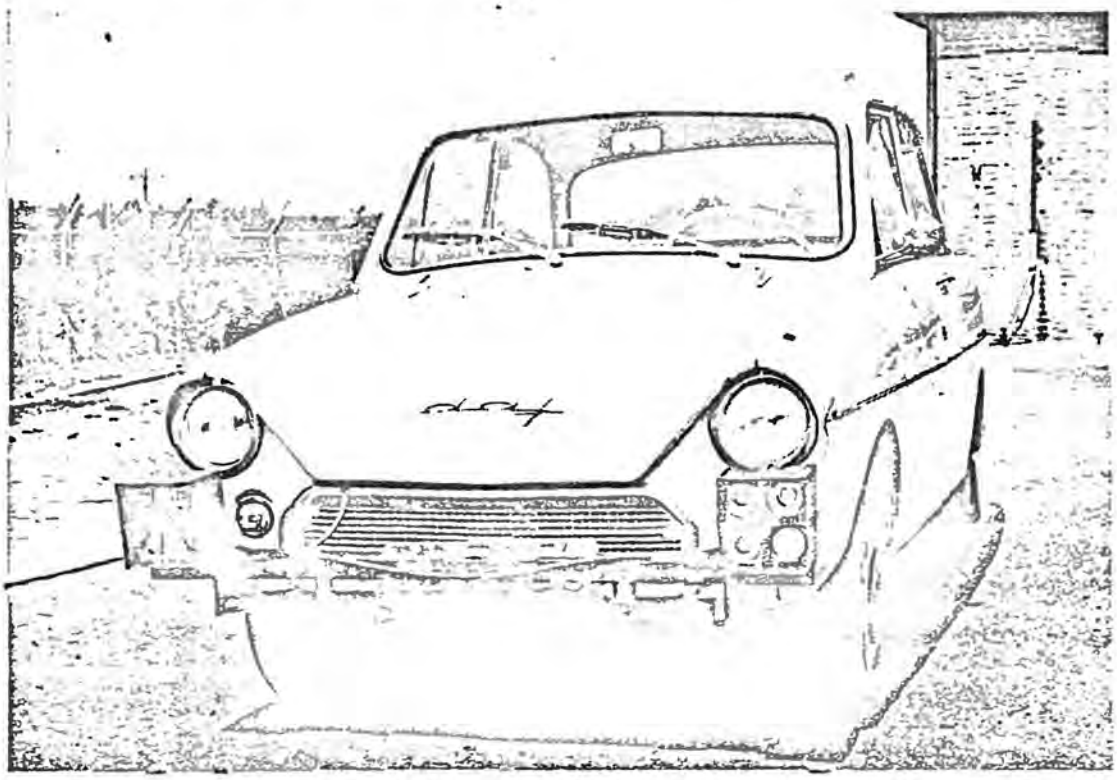


Figure 16

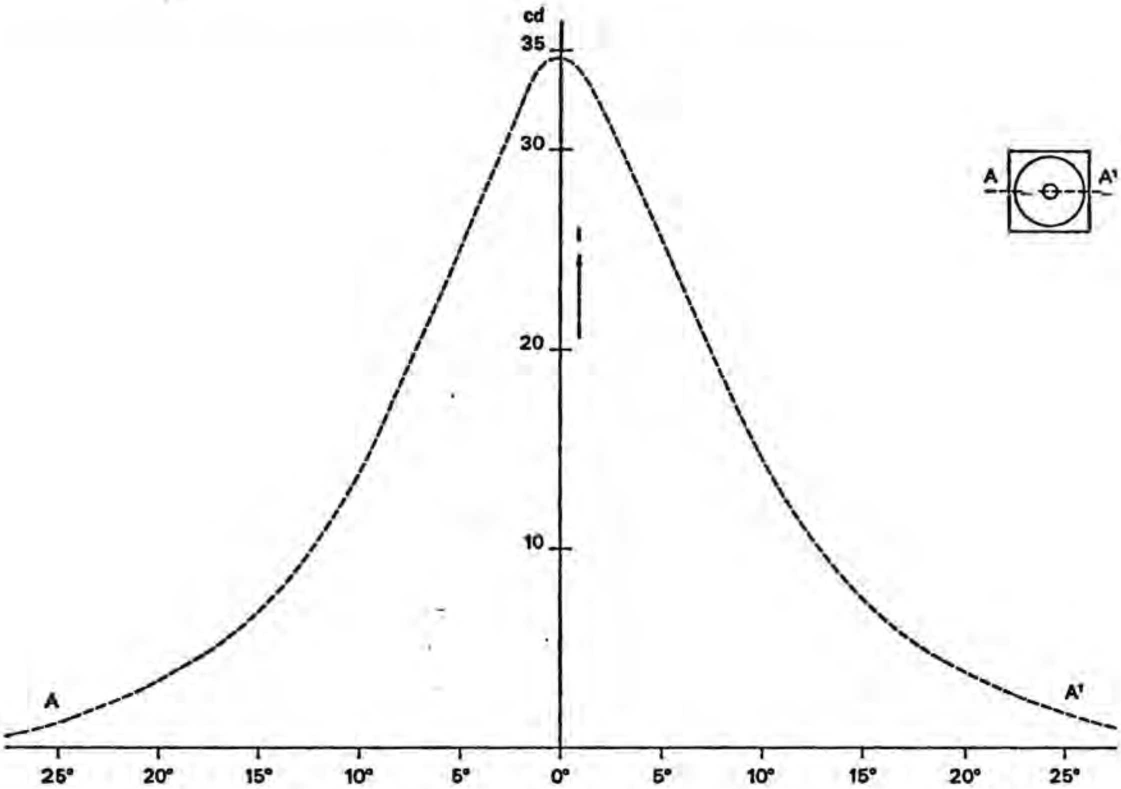


Figure 17

4.1.3. The road

The experiments were made in the open-air laboratory near Eindhoven. Figure 18 shows a plan of the lighting installation. Seen from the observers' post, the lighting columns were on the right and the car drove on the left. The columns had been fitted with cut off lanterns with incandescent lamps.

The effective road width was 14 metres. Three street-lighting levels were used in the night-time tests. See Table 11 and Figures 19 and 20.

On the left side of the road there were three tubes connected with pneumatic switches.

The test leader chose one of these switches each time; when the car drove over the tube in question, the switch was briefly connected. This switched on the shutter system dealt with below. To prevent disturbances, the tubes were laid out as V's and provided with two switches connected in parallel (Figure 21). The distances from the tubes to the observers were 45, 55, 70, 120 and 155 metres.

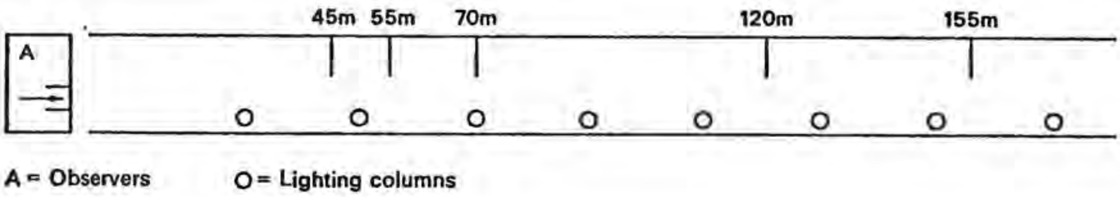


Figure 18

4.1.4. Observations

The seven observers (ages 25 to 35) stood in the observation cabin. In front of each was a screen with a shutter that was usually closed so that the road was not visible (Figures 22 and 23).
When the car drove over the tube chosen by the test leader, a synchronous motor was started which first operated a buzzer via a disk with cams and switches. One second later switched on the revolving magnets which then opened the shutters in front of the observers. These shutters remained open for 0.5 sec. This time was chosen for the following reasons: with longer times a 'point' in the road is no longer properly defined; with shorter times the movement of the car could not be observed. The observers now had to indicate by means of a two-way switch whether, under the disclosed conditions (intensity of car lights, speed, level of street lighting), they would still cross in front of the approaching car or not. The observers had to imagine that the road they would have to cross was 7 metres wide and had a refuge, and that they thus had to allow for traffic from one direction only. The observers' decisions and the time they needed to take them (the decision time) were noted by an eight-channel recorder.

4.2. Results of experiments

The four intensities of car lights, the three road-surface luminances, the three speeds and the five distances give a total of 4 × 3 × 3 × 5 = 180 combinations. Each combination was shown once, in random order, divided between two successive evenings.
Furthermore, a series of supplementary experiments was made in bright daylight (sunshine) and with no car lights. Hence, there were then only two variables, viz. speed and distance, and 3 × 5 = 15 possibilities. These day-time observations took place after the night-time observations. The results of the day-time measurements cannot therefore simply be compared with those of the night-time measurements because the possibility of learning effects must be allowed for.

Level	L	L right	L left	Diagram
1	none	none	none	none
2	0.19 cd/m²	0.36 cd/m²	0.04 cd/m²	19
3	1.0 cd/m²	1.45 cd/m²	0.50 cd/m²	20

Table 11

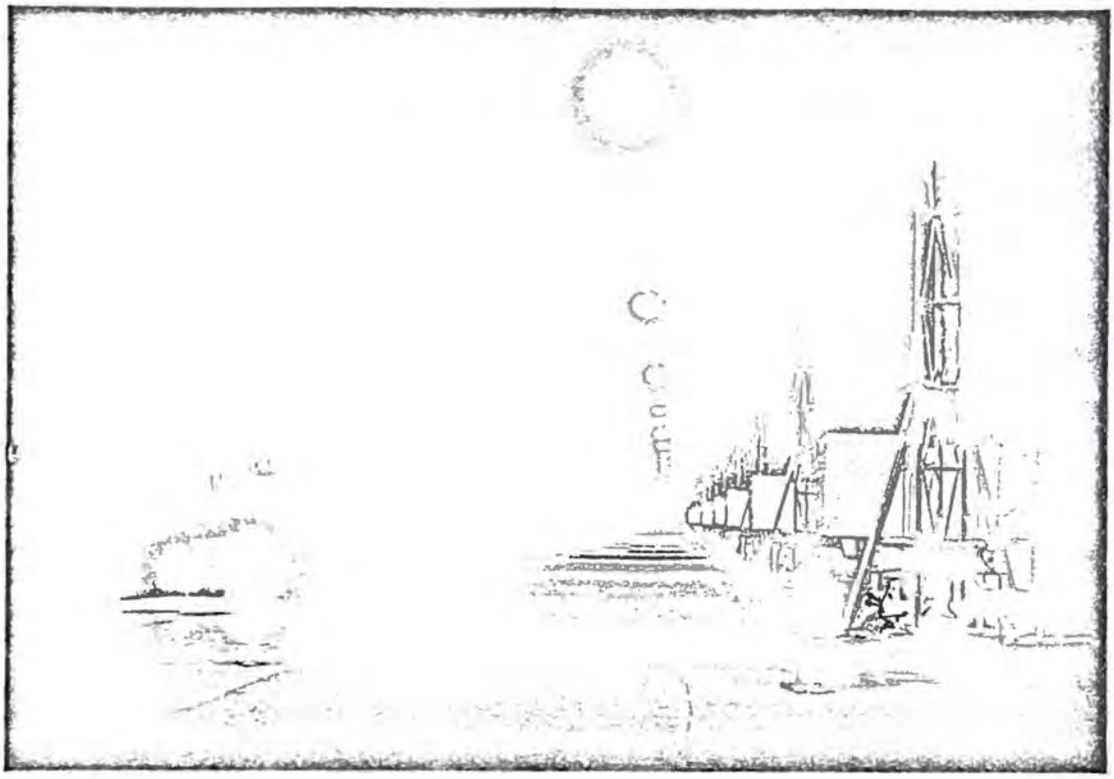
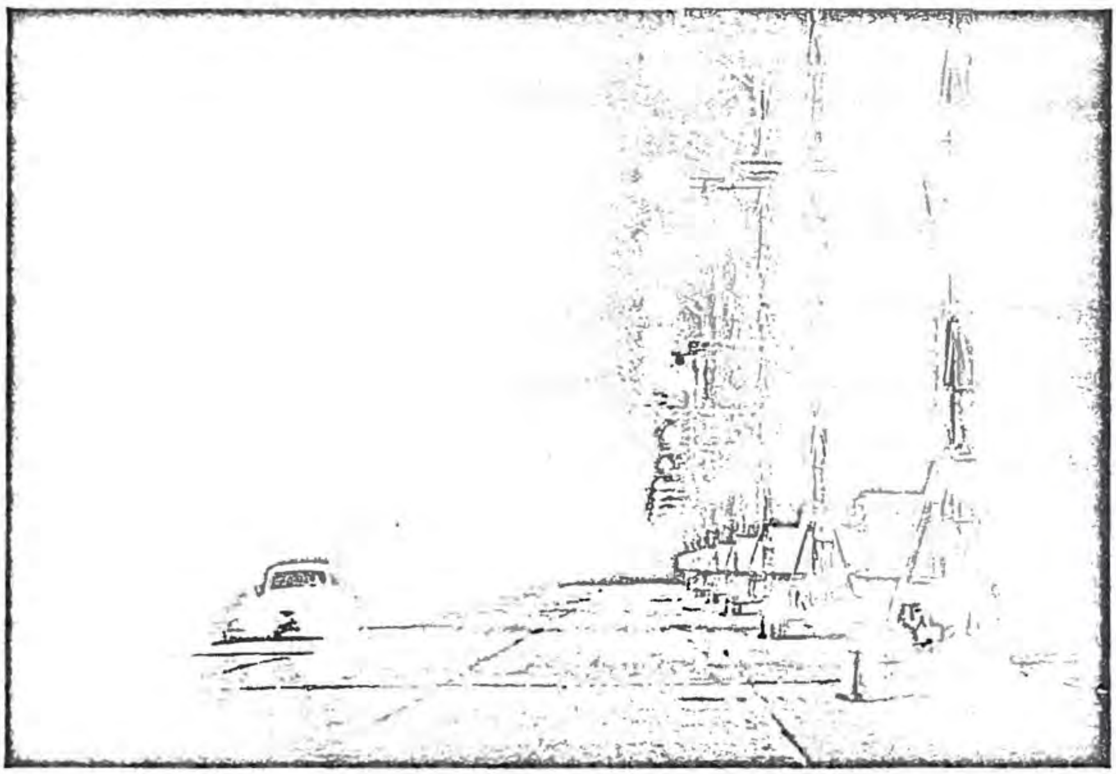


Figure 19 △

▽ Figure 20



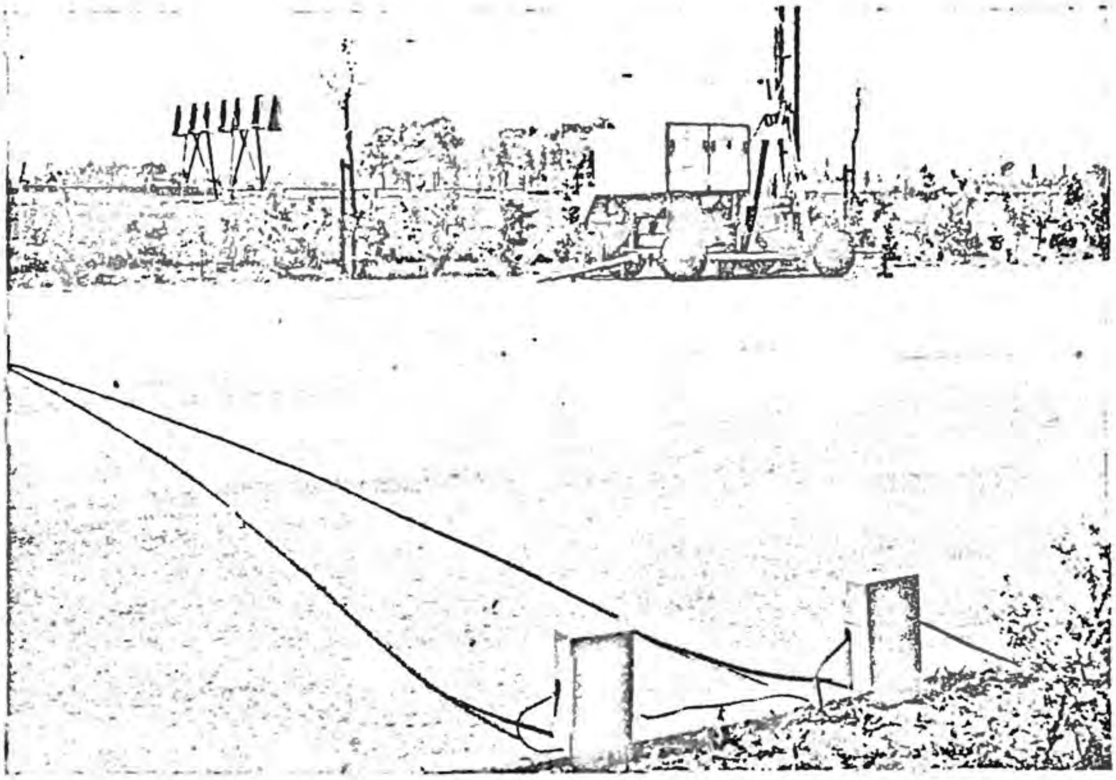
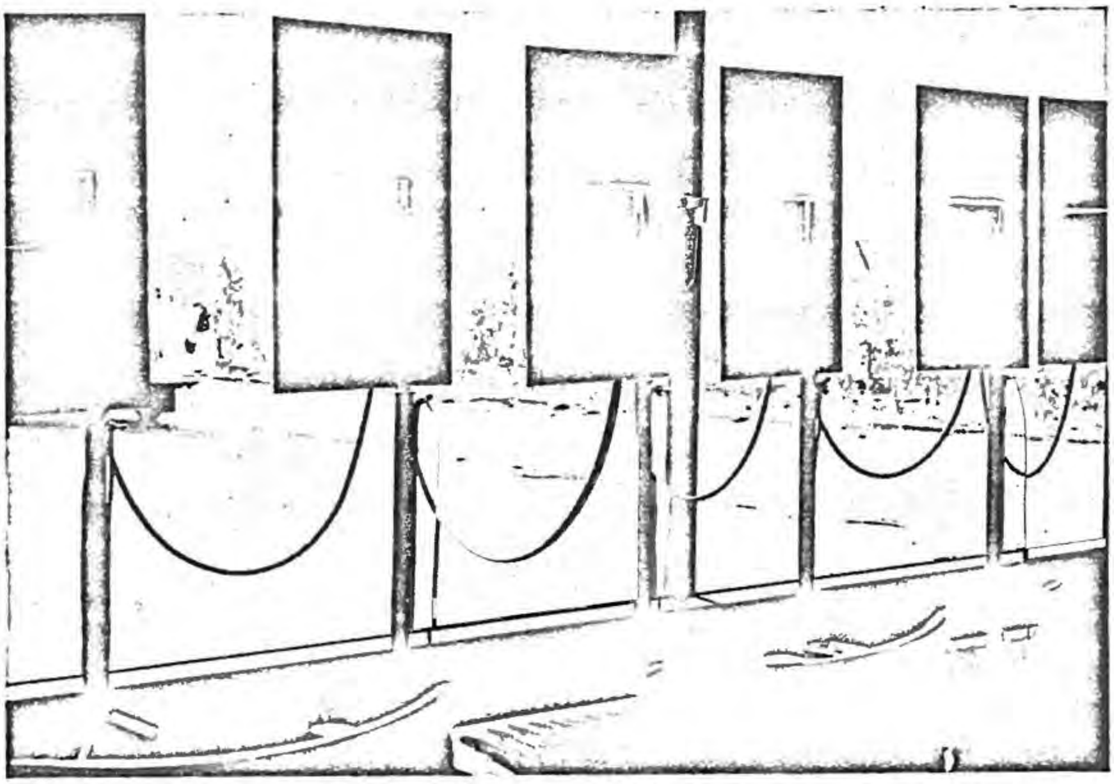


Figure 21 △

▽ Figure 22



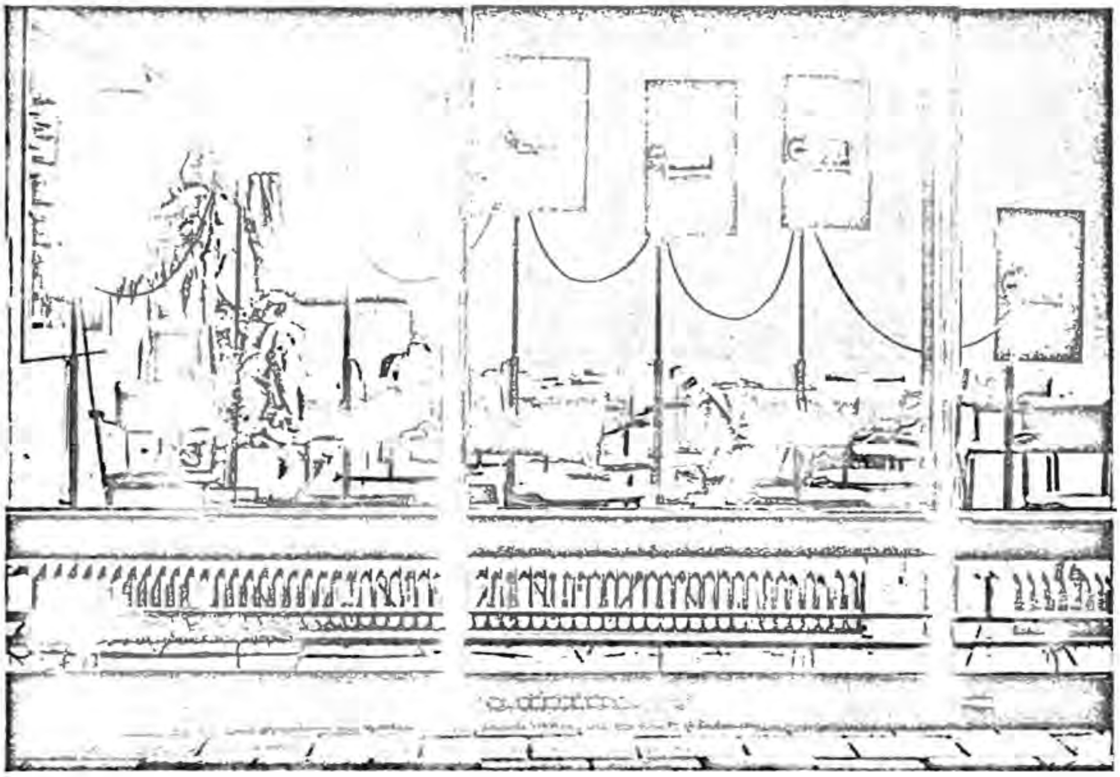


Figure 23

The shutters were opened one second after the car had passed the tube. The distance from car to observer therefore depended on the car's speed. Following the reasoning of 4.1.1. and in order to make the results more easy of reference, the available time was used instead of the distance itself. This is the time the car would need to reach the observers, driving at a constant speed after the shutters were opened. It is thus the time available for the pedestrian to cross. The times for the various distances and speeds are given in Table 12. For each combination of light intensity—street lighting—speed, the percentage p of positive decisions was now plotted as already indicated, in a diagram, against the available time t. An example is given in Figure 15 (page 51). The points in this diagram were joined by eye with the 'best' straight line. This straight line is described by the t value for p = 50%, and by the slope. The t value for p = 50% is indicated as 'average time t_m'.

The scatter between individual observations is fairly great. In order to obtain an idea of the influence of the different variables on the 'average time', the averages were determined for all variables, with one variable kept constant. Table 13 shows the appropriate average values of t_m, the slope and the decision time. It also gives the averages for the day-time measurements, although these are not directly comparable with the night-time measurements. Lastly, it gives the standard deviations.

Speed	Distance				
	45 m	55 m	70 m	120 m	155 m
30 km/h	4.4	5.6	7.4	13.4	17.6
40 km/h	3.1	4.0	5.3	9.8	12.9
50 km/h	2.2	3.0	4.0	7.6	10.1

Table 12. Time available in seconds.

Conditions	Description	t_m (sec)	Slope	Decision time (sec)
Light 1	0.3 cd	5.2 ± 0.3	0.72 ± 0.03	1.01 ± 0.03
2	3 cd	5.5 ± 0.2	0.67 ± 0.05	0.96 ± 0.03
3	30 cd	5.3 ± 0.2	0.66 ± 0.03	0.95 ± 0.03
4	300 cd	6.5 ± 0.2	0.69 ± 0.04	0.97 ± 0.04
Level 1	0 cd/m²	5.6 ± 0.3	0.71 ± 0.03	0.98 ± 0.03
2	0.2 cd/m²	5.8 ± 0.2	0.68 ± 0.03	0.96 ± 0.03
3	1.0 cd/m²	5.5 ± 0.2	0.67 ± 0.03	0.97 ± 0.03
Speed 1	30 km/h	5.9 ± 0.2	0.75 ± 0.04	0.94 ± 0.03
	40 km/h	5.8 ± 0.3	0.68 ± 0.03	1.00 ± 0.03
	50 km/h	5.2 ± 0.2	0.62 ± 0.01	0.97 ± 0.03
Day-time		5.0	0.74	0.80 ± 0.03

Table 13

4.3. Discussion

It must be emphasised that any conclusions that can be drawn from these measurements relate, of course, only to the conditions existing during the experiments. These differ substantially on some essential points from those in normal traffic. Firstly, in the experiments only a single car can be seen on the road. Even the lowest-intensity lights are then quite visible. Moreover owing to there being no other traffic they are always detectable as a car's side lights; their detectability and conspicuousness are not obstructed by other lights. Furthermore, the observers were warned that a car was coming; and at the moment of observation they also knew fairly well the direction where the car was. On these points the conditions of the experiments were better than in normal road traffic. The decision is based on a single, brief observation. Repeated observation, and if necessary correction of the decision, was not possible in the experiments. In this way, therefore, actual conditions are better. The outcome may possibly be influenced by the fact that the observers take no risk if they are reckless, while on the other hand they may be overcautious. But neither being reckless or over-cautious is likely to be systematically related to lighting conditions, and the results can thus be used for comparison of the latter.

With this proviso, it can be inferred from Table 13 that the average time (t_m; the time in which a positive decision is still taken in 50% of the observations) is not significantly related to the intensity of car lighting if it is between 0.3 and 30 cd. At high intensities (300 cd), t_m becomes significantly greater. This might be interpreted as follows: owing to the great intensity of its lights, the car seems to be closer than it really is. In view of the scatter, no influence of intensity of car lights can be noted upon the slopes or the decision times (and the consequent degree of uncertainty in the decision).

The road-surface luminance levels used for this purpose have no demonstrable influence on judgments. The whiteness of the car may have played a part: with low road-surface luminancies the lights were easy to see and with higher luminancies also the car itself. In the day-time measurements, smaller t_m and decision-time values were found. Possibly learning effects play a part in this.

Speed has some influence on the outcome. It cannot be ascertained whether this is due to the limited observation time. In view of the scatter in individual observations, no interactions can be demonstrated between the variables. The influence of any interactions is unlikely to be great, however.

4.4. Conclusions

1. In the experimental conditions, the decision whether to cross is not demonstrably related to the intensity of an approaching car's lights if this is greater than 0.3 cd and less than 300 cd.
2. In the experimental conditions the choice is not demonstrably related to the street-lighting level.
3. If the conflict conditions of lighted vehicle/crossing pedestrian are also influenced by the intensity of the car's lights then, by elimination of alternatives, this conflict is likely to result from the simultaneous appearance in the field of vision of vehicles carrying lights of very different intensities.
4. Conclusion 3 indicates a need for uniformity in vehicle lights. This is a subject for further research into optimum intensity and the width of the margin permissible around this optimum without detracting too much from uniformity. As already indicated the position of this optimum is determined firstly by the desire to have the highest possible intensity for maximum conspicuousness, and secondly by the desire for low intensity to avoid glare.

Appendix I Statistical research

The possibility of observing side lights and low-beam headlights

Four observers took part in this research. The observations were divided between two half hours; the first half hour was in dry weather, the second in rainy weather.
Figure I.1. shows the respective positions (I, II and III). At X there was an extra observer who only counted the number of passing motor vehicles.
The results are given in Table I.1. During the first half hour's observations various difficulties were found to occur; among other things, the low-beam headlight of one type of car was judged by one of the observers to be a side light. In this period, therefore, there were differences as between observers II and III ($\chi^2 = 0.171$; df = 1; $0.50 < P < 0.75$).
After clear instructions had been given about the problematic observations, the difference in observations practically disappeared. In the second half hour, therefore, even in spite of the rain, there was no longer any material difference as between observers II and III ($\chi^2 = 0.009$; df = 1; $0.90 < P < 0.95$).

Note: Observer I's results are not included in these calculations because he did not count vehicles coming from the side street.
From the counts by observer I and the control X it was noticed that having to distinguish side lights and low-beam headlights does not produce incorrect total counts.

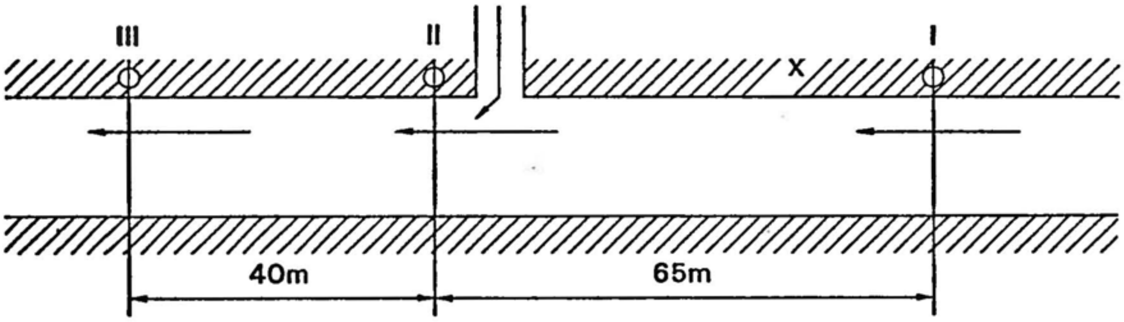


Figure I.1.

	Vehicle lighting	Obs. I	Obs. II	Obs. III	Obs. X
1st half hour (dry)	side lights	356	353	363	
	low-beam headlights	114	114	110	
	total	470	467	473	469
2nd half hour (rain)	side lights	277	276	278	
	low-beam headlights	94	114	113	
	Total	371	390	391	372

Table I.1. Results of observations.

Appendix II Statistical research

Pilot study into use of side lights and low-beam headlights

The primary object of this pilot study was to ascertain whether driving with side lights or low-beam headlights was related to the day of the week. In Utrecht and the control cities, Amsterdam, The Hague and Groningen, therefore, counts were taken every day for one week.
In the second instance this pilot study examined whether the suppositions were correct that the type of road and quality of street-lighting had a substantial influence on driving with side lights or low-beam headlights.
Table II.1. gives the results of counts in Utrecht only. (The figures for the other cities have been omitted; they add no more information, and the conclusions are the same as for the Utrecht figures.)
The results do indeed show such differences between the different days that it is advisable to allow for these in the actual research.
This conclusion was arrived at by calculating the expected number of side lights and low-beam headlights with the aid of the marginal totals for each day, and comparing this with the actual value. ($\chi^2 = 17.86$; df = 6; $P < 0.01$).
The results also show that there is most probably some influence on the use of side lights and low-beam headlights due to type of street and quality of street lighting. It proved impossible, with the limited figures available, to show this relationship with any statistical significance. It is nevertheless assumed to exist.
It was consequently decided to include these factors in the actual research as independent variables.

Day of week	Date	Main roads into town				Distributing roads			
		poor lighting		good lighting		poor lighting		good lighting	
		number of side lights	number of low-beam headlights	number of side lights	number of low-beam headlights	number of side lights	number of low-beam headlights	number of side lights	number of low-beam headlights
Sunday	1-11-'64	141	95	266	225	106	139	531	240
Monday	2-11-'64	181	105	255	260	105	107	607	237
Tuesday	3-11-'64	174	129	364	297	132	146	664	219
Wednesday	4-11-'64	206	88	265	208	110	114	630	188
Thursday	5-11-'64	175	149	289	193	106	107	695	232
Friday	6-11-'64	189	170	294	276	140	156	679	208
Saturday	7-11-'64	141	137	204	203	121	102	522	177
Total numbers		1207	873	1937	1662	820	871	4328	1501
Total percentages		58%	42%	54%	46%	48%	52%	74%	26%

Totals	side lights	low-beam headlights	Total
Well-lighted streets	6265	3163	9428
Poorly-lighted streets	2027	1744	3771
Total numbers	8292	4907	13199
Total percentages	63%	37%	100%

Table II.1. The use of side lights and low-beam headlights in Utrecht. Time: 7.30 p.m.–8.30 p.m.

Appendix III Statistical research

Factors influencing use of side lights and low-beam headlights

Statistical basis

As the number of count days for wet and dry road surfaces was not the same (14 dry and 8 wet), the 'contrast coefficients' must first be determined for the C-effect, the AC-, BC- and ABC-effects (See Table III.1), to obtain suitable figures for normal variance analysis [19].
With these coefficients, the denominator for the sum of squares of the C-effect can be calculated. A variance analysis can then be made. The results are given in Table III.2.
Testing the residual variances against effects AC, BC and ABC gives no significant differences and hence these variances can be combined into one new variance against which the other effects are tested (Table III.3). The F-values for A, B and AB effects are then found to be very significant.
Another method of equalising the count days for dry and wet road surfaces is that of first transforming the percentages with the aid of the: sine of arc $\sqrt{\text{observation}}$ [20]. After a variance analysis, however, the conclusions remain the same.
Applying variance analysis presupposes, inter alia, that the variances of the various series of observations come from the same normally distributed population and do not differ significantly. This can be investigated by comparing the variances within the series of observations and looking up the appropriate significances in an F-table.
It is then found that the assumption 'all variances are alike' is not right. Consequently, the variance analysis cannot in fact be applied, or else the results must be used with caution.
In order to examine the value of the conclusions from the variance analysis, the following verification was made.
1. The average values and variances were calculated for all series of observations (expressed as percentages of low-beam headlight drivers).
2. The variances were compared with the F-test.
3. Where significant differences ($P < 0.05$) occurred, the average values were next compared with the t-test.
4. Lastly, these t-values were used to determine the series of observations showing significant differences.

Comparison of all possible combinations finally leads to the following conclusions:
1. The quality of the street lighting (= effect B) has an influence on driving with low-beam headlights.
2. The type of street also has a slight influence on driving with low-beam headlights (= effect A), especially in poorly-lighted streets (= effect AB).
3. Road-surface conditions appear in these experiments to have no influence on driving with low-beam headlights.

These verifications show that the results of variance analysis are sufficiently reliable, even though the basis material is not entirely satisfactory.

	(1)	c	b	bc	a	ac	ab	abc
C	−8	−14	−8	−14	−8	14	−8	14
AC	8	−14	8	−14	−8	14	−8	14
BC	8	−14	−8	14	8	−14	−8	14
ABC	−8	14	8	−14	8	−14	−8	14

Table III.1. Contrast coefficients for C-, AC-, BC- and ABC- effects.

	Sum of squares	Number of degrees of freedom	Variance
A	976.223	1	976.223
B	1907.433	1	1907.433
C (corrected)	20.455	1	20.455
AB	402.919	1	402.919
AC	6.975	1	6.975
BC	0.081	1	0.081
ABC	55.530	1	55.530
residue	2176.27	80	27.203
total	5545.889	87	

Table III.2. Variance analysis.

Effect	$F (= s^2 \ldots / s_1^2)$	P
AB	14.937	$P \ll 0.001$
A	36.191	$P \ll 0.001$
B	70.714	$P \ll 0.001$
C	0.758	$0.50 < P < 0.70$

Table III.3. Testing with a new variance ($s_1^2 = 26.974$; df = 83).

Appendix IV Statistical research

Testing differences between percentages of low-beam headlight drivers

The differences in the percentages stated in Table 10 were investigated as follows: Based on the observations, values p_1 and p_2 can be calculated as follows:

$$p_1 = \frac{\text{number of low-beam headlight drivers involved in accidents}}{\text{total number of drivers involved in accidents}}$$

$$p_2 = \frac{\text{number of low-beam headlight drivers observed}}{\text{total number of drivers observed}}$$

The corresponding population parameters are P_1 and P_2. The differences between p_1 and p_2 are now tested with the hypothesis that $H_0: P_1 = P_2$. The confidence interval within which the difference between P_1 and P_2 must lie can be calculated from the observations as follows:

$$p_1 - p_2 - z_{1/2\alpha}\sqrt{\frac{p_1(1-p_1)}{N_1} + \frac{p_2(1-p_2)}{N_2}} < P_1 - P_2$$

$$P_1 - P_2 < p_1 - p_2 + z_{1-1/2\alpha}\sqrt{\frac{p_1(1-p_1)}{N_1} + \frac{p_2(1-p_2)}{N_2}}$$

in which:
N_1 = total number of drivers in accidents
N_2 = total count of drivers

If the Null value is within these limits, there is no reason for rejecting the H_0 at the $100\alpha\%$ level [21].

Calculations with the above formula give the following results for the percentages in Table 10:

Utrecht: $0.149 < p_1 - p_2 < 0.211$. H_0 must therefore be rejected: $p_1 \pm p_2$; there is a significant difference (tested at 95% = confidence level).

The Hague; $0.048 < p_1 - p_2 < 0.072$ (Same as for Utrecht).

Groningen; $0.250 < p_1 - p_2 < 0.350$ (Same as for Utrecht).

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