PUBLIC LIGHTING: THE EFFECTIVENESS FOR ROAD TRANSPORT

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SUMMARY

Drivers have a dual task in traffic, the parts of which overlap only in part: to arrive at the destination of their trip, and to do so without collisions. One of the major functions of public lighting is to support traffic participants (drivers) in performing these tasks at night. The presence and quality of public lighting may therefore be justified by applying a "supply-and-demand" model: the supply of lighting should exceed or at least equal the demands for the specific task aspects under consideration.

Preliminary research results related to the first task aspect suggest that the run of the road - permitting a considerable preview time - is the crucial road characteristic that must be rendered visible.

The second task aspect is dealt with in accident studies. An overall result is that good lighting compared with pooor or absent lighting on major urban roads may yield a 30% reduction in night-time injury accidents. The relation between accidents and the quality of lighting - required o.a. to specify "good" and "poor" is still under investigation. The influence of the traffic and the infrastructure requires more insight in the classification of roads and streets.

The dual-task approach leads to suggestions for the quality and quantity of public lighting that are better founded and more generally applicable than the traditional standards.

1. INTRODUCTION

Under the present conditions, road traffic is impossible without a large amount of visual information, which has to be acquired in "real time" from the surroundings. This notion is so strong that it seems justified to say that the present day road traffic (and its hardware and software) is mostly concerned with the acquisition of information. This does not only hold for the infra-structure, the run of the road and the road markings, but also for the traffic management, the traffic education, the equipment of vehicles, the signing, etc. In all these cases, the standard situation is the day situation, and - even more restrictive - the day situation when visibility is good (no fog or haze or twilight) and the weather is good (no rain, snow, etc.). Finally, the standard requirement on the road traffic system and its equipment is based on a "normal" observer - i.e. no visual impairment, no fatigue or alcohol intoxication etc. All other situations are really considered as "exceptions" even if this is not usually expressed as such.

For these standard situation the equipment of the traffic system has to fulfil certain requirements. We will not discuss these requirements any further. Nor will we discuss the exceptions that have to do with restricted meteorological visibility or driver impairment, in spite of the fact that these restrictions and impairments probably are responsible for the majority of road traffic accidents. We will concentrate on one "exception": the absence of (natural) daylight. When daylight is absent, the acquisition of visual information is not possible. Road traffic of the nature we are accustomed to today is not possible either: some sort of artificial light is indispensable. This artificial light is therefore a road traffic requirement: without artificial light of any kind, night-time road traffic is not possible.

When we discuss the requirements for such lighting, we will have to look into the task of the traffic participant. As the requirements are severest for the drivers of motor vehicles, we will concentrate on them. The task (the driving task) is in fact a dual one. The first part (or subtask) is based on the need to arrive at the destination: when one does not arrive at the destination, the trip is not really a part of transportation. The second subtask is to avoid collisions during the trip. All accidents, even the slight ones, interfere with the success of the trip, and usually they obstruct the arrival at the destination.

The first subtask relates to the need to arrive at the destination. When we discuss driving a car, it seems logical to assume that the trip should be made in a fashion becoming to a car, i.e. with a reasonable speed and with a reasonable degree of comfort. In order to form an idea of what is to be understood as "reasonable" let us think of traffic along a lightly trafficked, rural road without any furnishings. In order to be able to proceed with a speed of say 50 km/h in the dark, some form of lighting is required. We might call this lighting the "basic lighting". Over the decades a system has been developed that fulfils the requirements: all cars are equiped with low-beam headlamps, and these headlamps permit the drivers to proceed at the required speed along the road. A large amount of development did result in a system that is nearly perfect for these conditions. One must, however, not expect that this low-beam system is anything like perfect under circumstances that are quite different: low beams perform very poorly in urban, well-lit streets, and they are most inadequate for high speed, densily trafficked roads, even more so when those roads are for mixed traffic. In all these cases quite different lighting is needed, e.g. fixed overhead lighting, or fully different measures like separation of modes of traffic participation, or applying dual-carriageway roads. We will not discuss with these measures: we will concentrate on another aspect where the "basic lighting" (the low beams) is insufficient: we will concentrate on the second subtask.

2. TRAFFIC ACCIDENTS

When a driver takes part in road traffic, he (or she) has a quite distinct set of goals and plans. Not only has the destination, the socio-economic trip motivation and the mode of transport been decided upon; also the major part of the route selection and the general ideas about driving speed and degree of acceptable risk has been assessed before starting. In short the driver has a quite detailed plan about what he wants or expects. Now, wants and expectations may be interfered with, or even be obstructed, by sudden, unexpected and unwanted incidents. These incidents are not always consequential; however, particularly in motorised traffic there are many incidents that might result in collisions, and that require certain evading manoeuvres on the part of the driver to avoid the collisions. Other incidents, that would not lead to accidents if the drivers did not execute avoiding manoeuvres will be disregarded.

The incidents that may result in collisions have a number of special characteristics: they are sudden (otherwise they would have been regarded as part of the Task I), they are unexpected and not predicted and they are unwanted: they require the driver to depart from his original plan. To make this important point quite clear: if the avoiding manoeuvre did not conflict with his plans, it would again be part of the Task I. In this way, the distinction between Task I and Task II is really a formal one; this allows us to define all avoiding manoeuvres as part of Task II and all other aspects of driving behaviour as part of Task I. We can even go further: we can consider all collisions as situations where the avoiding was not successful. It might not be (physically or psychologically) possible to have a successful avoidance manoeuvre: the fact that a collision took place is sufficient to state that the avoidance was not successful. It is for this reason that we speak of collisions: no collision means no accidents. Obviously, this approach leads to a very specific definition of the concept of traffic safety; a definition that is more restricted than some definitions used in other contexts.

The avoidance of collisions requires specific actions from the part of the driver: coping behaviour (coping with emergencies). As we have seen, these actions are different from the ones that are part of the drivers' original plans. The driver is thus required not only to decide to perform that particular coping behaviour; he also - and prior to it - must decide to deviate from his original plan. Obviously these decisions require a special motivation. We will not go in these psychological aspects of this question, how essential they might be. We will concentrate on the aspects of visual perception and will point out that because we deal here with unexpected incidents, the requirements put on the surrounding are more severe than when dealing with "normal" traffic (Task I).

Measures to avoid incidents become collisions are abundant. The most obvious group consists of those measures aimed at abolishing completely that type of incident: grade and mode seperation, signalling, dual-carriageway or one-way roads, etc. Under the present conditions these measures are not always feasible. We will deal here with the public (overhead) lighting as a collision countermeasure.

In all cases the analysis of traffic accidents delivers the basic data for the considerations. The analysis of traffic accidents is a difficult and controversial matter. The statistics can never be better than the data they are based upon, and it is well known that the data on accidents are not very accurate. Primarily, usually only fatal accidents are reported with adequate accuracy and adequate covering: in the Netherlands the registration level of fatal accidents is over 97%. Because, however, the number of fatal accidents is rather small (some 1800 per annum) they can hardly be used for studies where one deals with rather specialised measures, i.e. small subgroups of accidents. Therefore one is usually obliged to use the injury accidents as well; the degree and the accuracy of reporting of this group of accidents are, however, far inferior to those of fatal accidents. In spite of the fact that in the Netherlands annually some 60,000 injury accidents are reported, the number is still too small for accurate statistical statements regarding small subsets of accidents. The number of damage-only accidents (300,000 annually reported, but estimated as being well over one million) might seem large enough to justify precise statistical statements; however as the gathering of the data and the level of reporting are very poor, they cannot be used as a basis for scientifically justified studies. This implies that the result of all accident statistics should be regarded as rough indications only. There are two exceptions: first, accident studies that involve overall, national data - such as studies regarding seatbelt usage - may yield accurate predictions. Secondly, if a great number of separate studies, that individually do not prove anything at all, are very consistent in their results, the overall result may be used as a valuable indication; more particularly if the studies cover a wide range of methods, and are spread out over a long time and many countries. This seems to be the case with the studies that deal with the effect of public lighting as an accident countermeasure.

3. THE EFFECTIVENESS OF PUBLIC LIGHTING

During the last four decades, a large number of studies has been set up where the accidents with very poor or absent road lighting were compared with the similar situation - usually on the same roads - with adequate lighting. Very few of these studies were large enough to indicate on their own a statistically significant result; furthermore, the relevant data are not always reported precisely enough to form an accurate picture of the experiment. However, because the studies are very consistent in their results, it seems justified to consider it as an scientific fact that a good public lighting, compared with very poor lighting or no lighting at all, will lead on major urban thoroughfares to a reduction of some 30% of the night-time injury accidents.

This conclusion is drawn from the amassed individual studies. During the years a number of surveys containing these studies have been compiled. The first was CIE (1960), a famous report that is presently being revised and updated: the new CIE report may be regarded as a conclusive study (CIE, 1983). Also the OECD took this matter to heart: reports were published in 1971 and 1980; see also Brühning & Weissbrodt (1981). The OECD studies were primarily restricted to those studies that were complete in their description, more in particular as regards the methodology applied. Finally, the Institute for Road Safety Research SWOV in the Netherlands prepared a report that aimed at completeness: apart from the well-know, well-documented studies, also a number of smaller and sometimes less well-described studies were included. This collection therefore includes "ripe and green" and is not restricted to the "ripe" studies (Schreuder, 1983). The result of all these compilations is very much the same: the conclusion quoted above is drawn and reconfirmed from all studies. Thus, we feel justified to announce this result as a scientific fact: on major urban thoroughfares a good public lighting may save some 30% of the night-time injury accidents.

One might add one more thing. In the past, studies of this type usually were set up by scientists or by authorities that were interested in justifying higher levels of public lighting: although no evidence of it is found, many people considered these studies as biased and therefore not very convincing. More recently, however, in the wake of limitations in the oil supply and of economic recessions, public lighting has been reduced on a large scale. And many studies have been set up to indicate that those reductions were of no consequence for the road safety. It is noteworthy that, these studies which might be suspected as being biased in the other direction, did not yield a substantially different result. The 30% reduction is therefore not just a hobby-horse of a lobby or a pressure-group! (Schreuder, 1983).

The studies that are the basis of this conclusion cover many hundreds of pages; even the compilations quoted above are often quite voluminous. It is not possible to survey all that material in a brief essay; we will restrict ourselves therefore to just giving a few examples; a far more complete survey will be given in the forthcoming CIE document, and for the full details one should look of course to the original publications.

The first study we quote is a classic: the large study from Great Britain (Anon, 1963). The major results can be summarised as follows:

- fatal accidents: reduction 45%
- injury accidents: reduction 30%
- injury accidents (pedestrians) 45%

The study included 64 sites where the lighting was increased from "poor" to "good" according the code of that time (BSI, 1952).

Similar results can be quoted from two other UK studies. The first one, reported by Zuman (1980) indicates on 19 sites where high speeds were permitted, a reduction of 50% for injury accidents, and 60% for severe injuries. Secondly, a study reported by Cornwell & Mackay (1972) for 16 urban sites, 43 rural roads and 42 trunk roads. Reductions of 38.0%, 36.9% and 28.1% were recorded respectively.

In the US, a number of studies were made. They have been reported by Box (1956, 1970, 1972) and Sielsky (1967). The results are conflicting, in such a way that the samples of roads were very heterogeneous, and the results have been presented not always in a clear way. We quote these studies because they have often been understood as indicating that a high light level could lead to more accidents instead of less. Box (1972) adds to the confusion by stating that "it appears possible to "overlight" as well as to "underlight" a given street". This curious statement really is the result of the method whereby the accidents are summed up in whole urban districts, and not in separate streets. Furthermore, the assessment of the lighting level is questionable, and all influence of travel is disregarded.

A more important set of studies has been made in Australia. Turner (1962) did find a relationship between the night/day ratio in (all) accidents and the installed luminous flux (in lumens per 100 ft of road):
$N/D = 1.53 - 0.236 \log \phi$.
For a transition from "poor" to "good" lighting this means a 30% reduction in the night-time accidents. Thorpe (1963) gives similar data: from "poor" to "good" or "very good" the reduction for all accidents is 21% and for injury accidents 34%. Skene (1976) gives in a more modern study a more complicated formula:
$N/D = 0.844 - 0.167 \ln (LHF/sw)$
where LHF is the lower hemisphere lantern flux, and w and s the road width and the spacing. This corresponds with a reduction of injury accidents of 29% (Fisher, 1977).

The studies given here as examples were all of the before-and-after type: the accidents in the before period were compared with the accidents on the same roads after the change-over (usually the installation or upgrading of the public lighting). This type of study may yield trustworthy results, provided care is taken to correct for general trends (in traffic, regulations, economy or weather). For these corrections, controls are required, controls that were absent in virtually all studies quoted here. Again, it is the bulk of the results that suggest a hard, underlying fact.

4. THE INFLUENCE OF THE LIGHT LEVEL ON ACCIDENTS

In the studies quoted above, the accidents from the before period, under "poor" lighting, have been compared with the accidents in the after period, when the lighting was "good" without specifying "poor" and "good". In other words, it is essential to find out how good is "good"; and supposing that there is a "law of deminishing returns", what is the optimum light level above which no substantial further improvement may be expected. This, obviously, is a much more difficult matter to investigate; one must include a (large) numer of different light levels in the excercise. As might be expected, only a small number of studies has been reported; and from these we will quote only three examples. In all cases the light level is expressed in the average road-surface luminance in accordance with CIE practice.

The first is a curious Swiss study, where the luminance levels were quite high - much higher than encountered in practice, viz. between 2 and 5 cd/m^2. There was found a clear reduction in night-time accidents with increasing light level; surprisingly, the reduction seems even to continue for values over 5 cd/m2! Because no other studies were made at these high values, it is not certain whether these results may be generalised (see Walthert & Hehlen, 1980).

A second study has been made in Philadelphia (Penn., USA). This study has been widely publicised; a summary of the main findings is given in Janoff et al. (1977). The study was concerned primarily with the relationship between driver behaviour and the visibility. In this respect the study yielded interesting information, but it was far from conclusive. This was discussed elsewhere in detail (Schreuder, 1983). We quote the study here because it did include an accident analysis, the results of which could be expressed as follows:

$$N = 1.52 + 2.67(a) + 0.0000855(b) + 1.26(c) - 0.415(d)$$

where:

N = the number of accidents

(a) = the location (city centre or not)

(b) = the urbanisation

(c) = 15th percentile of light level hFc

(d) = 15th percentile of visibility

(The definitions of these quantities are really rather complicated; the interested reader is referred to the original texts).
It is interesting to note that an increase in the visibility leads to less accidents, but that the light level is not included directly in the formula. One suspects that the light level is incorporated in the urbanisation values included in the formula - a confounding factor to be encountered quite often in this kind of study: Obviously, the local authorities responsible for the public lighting in a city or town recognise the need for different lighting levels in different streets, even if this is not quantifiable! It is precisely the aim of the type of studies reported here to give a quantified basis for these experiences!

This remark leads us directly to the last study we will quote: the well-known UK studies reported by Scott (1980) and Hargroves & Scott (1979). These studies deserve the title "classic" because of the extension and the very careful execution; however, there are a number of remarks to be made as regards the degree in which the results may be generally applied. The studies involved some 70 streets in the UK where all relevant lighting data and accident data were collected. The results could, between 0.5 and 2 cd/m^2, be fitted "best" by the following expression:
Dark/Day = 0.66 exp ($-0.42\ L_{av}$).
This expression includes all injury accidents, but when only the non-pedestrian accidents were considered, a curious thing emerged. On the one hand, the positive influence of the luminance level was reconfirmed, but on the other hand it seems that a "better" uniformity of the luminance pattern is "dangerous". The authors clearly did not know what to do with this: "The positive slope with increasing overall uniformity U_o is unexpected. The negative slope with increasing L is consistent with most other analyses in this study" (Scott, 1980, pp. 12). The relation in question is:
Night/Day = 0.5 exp ($1.49\ U_o - 0.75\ L$).

This brings us to our main point of criticism regarding this study: it is quite conceivable that there is a relationship between the lighting level and the "danger" of the road, more in particular the "night-time danger". In fact this is what one should expect if the local public lighting engineers have any idea at all what they are doing: providing the most difficult situations with the best available lighting - even if they cannot quantify the "danger". The obvious way out is to register the "danger" of the roads, either by asking the local authorities directly or by assessing the traffic and the infrastructure of the roads in question. It is precisely this that we are undertaking at present in the Netherlands; it seems that the progress is promising, although there are no data yet. In this way we expect to fill another gap left open by the UK study: we plan to include different types of road in the study, including residential streets and rural roads. In order to keep the size of the study manageable, we will restrict ourselves to rather general assessments of the lighting level and of the other parameters (traffic and infrastructure). The study is discussed in some detail by Schreuder (1980, 1983).

5. CLASSIFICATION OF ROADS

Every study, including roads of different types, requires some kind of classification of roads. Now, traffic engineering provides us with a wide variety of road classification systems. Unfortunately, those systems are of limited value when one only deals with public lighting studies. There seems to be a wide range of roads that forms the "grey middle part". This need not be subdivided for the usual traffic engineering studies, it includes a wide range of roads where according to both theory and practical experience, the quality and quantity of public lighting needs to vary. We are forced, therefore, to set up a classification system of roads, particularly suited for public lighting studies.

A large number of trials has been made. We will not discuss these here but come to a proposal that is based on the amassed considerations used earlier. It has been proved useful to apply four distinct approaches here: (1) the function of the road in the transportation network, (2) the type of infrastructure, more in particular the number of carriageways, (3) the percentage of origin-and-destination traffic, and (4) the overall traffic volume. In this way there can be set up a classification system that can be applied both for urban and for rural roads. An example is given in Table I. This table exhibits 24 different types of road - far more than the number of types of lighting installations that can sensibly be discerned. This implies that many road types will require the same lighting type - a thing to keep in mind when considering the fact that the road classification system proposed in Table I shows many areas of overlap and other aspects of limited precision. Practice in a limited sample showed, however, that it can be used.

An alternative that should be considered carefully is to have a classification of intersections rather than a classification of roads. The reason is that many accidents occur on intersections. As a point of fact, in the Netherlands in 1982, 35% of all accidents and 47% of all accidents within built-up areas were on intersections. This is for fatal accidents; for (severe) injury accidents the percentages are 45 and 51 respectively (CBS, 1984). Now, as an example the number of intersections within the jurisdiction in of the city of Rotterdam has been studied. The whole built-up area shows 7.5 intersections per km of road; the modern outskirts 7.0 intersections per km and the (old) city centre 9 intersections per km. An intersection, defined according to the usage in accident registration, including its "area of influence", covers some 50 to 80 m. Thus, about one-quarter to one-third of urban roads consists of intersections. In combination with the accident data this suggests that intersections are dangerous areas - just as one might have expected - but the predominance does not seem so great as to justify a completely new classification system based on intersections and not on roads, as is customary.

A survey-type of investigation, as suggested above and described elsewhere, requires much more data in an easily manageable fashion. Traffic and infrastructure can be measured, counted or even estimated to a sufficient degree of accuracy. The lighting data require some more precision, although not of a degree as applied in the "classical" British study. It is expected that the assessment of the average road illuminance is sufficient; if needed, this can be converted when the overall reflection of the road surface is known, to luminance. An assessment of the illuminance requires either direct measurements or calculations. Provisional trials suggest that calculations based on a simple lantern classification might prove to be accurate enough for the majority of cases - particularly for residential areas where the light distributions generally used are rather similar. This system, that is based on the well-known CIE light distribution classification (CO, SCO and NCO), requires further confirmation.

6. RECOMMENDATIONS FOR PUBLIC LIGHTING

The dual-task approach leads in a way towards the establishment of recommendations for public lighting that differs from the conventional approach. This conventional approach is based on the assumption that the aim of public lighting is to create as far as possible the same or at least a similar condition of visibility as is present at day - the "standard" situation as indicated in the Introduction. More precisely, this is quantified in the way an object of 20 cm square with a reflection of 20% is visible. This object was used so often in all kinds of treatises that it became (not fully justifiable) known as The International (or CIE) Standard object. The dual-task approach is different from this in two ways: firstly - as the word says - one has to consider two rather distinct tasks (or sub-tasks) and secondly the requirements are based on the concept of the decision-making process. Visibility requirements, and thus lighting requirements, are derived from the need to be able to make the proper decisions in time to implement them. When assumptions are made regarding the relevant driving speed and when the appropriate "reaction" time is taken into account, this requirement can be converted into a minimum visibility distance. As the term "visibility" usually is associated with the treshold visibility, we prefer the alternative term of "preview time". However, in fact the two terms mean the same.

The way in which recommendations for public lighting can be derived from this dual-task approach is still under consideration. Firstly, the task aspects need to be worked out further, more in particular as regards the influence of the "higher" aspects in the decision-making process - risk taking and risk evaluation; the relative relationships between decisions in different hierarchical task levels, etc. Secondly, it is not fully known what minimum levels are really needed for different types of road - a matter discussed briefly above. This is required in order to establish the relationship between task and visibility aspects on the one hand and accidents (collisions) on the other. Still, enough is known to justify some remarks. A final set of recommendations cannot be given at the present time, but some governing ideas can be expressed - more or less as an example. What follows should therefore be regarded as an example only!

We will deal with the Task I first. This task was related to the need to arrive at the destination of the trip; it has to do primarily with aspects of route selection and maintenance, and on a more limited scale, with what is indicated in public lighting as "visual or optical guidance". Here we make a distinction in the information needed to adjust the speed and to adjust the lateral position on the road.

For adjustments of the speed, the required preview distance (or preview time) is quite large. On practical grounds one usually takes a few hundreds of metres. When the change of speed may be considerable, as may be expected at motorway intersections, if a new route has to be selected, usually one takes a preview distance of 1.5 to 3 km. Obviously, at such a distance the road itself simply is not visible. Marking and signalling are essential, both at day and during darkness. The visibility requirements for such signals fall outside the scope of this study. It should be stressed that all measures are based on common sense and practical experience: scientific research is nearly completely lacking. The practical experience leads to the generally accepted idea that, provided the markings on the road and on the vehicles are adequate, no (overhead) public lighting is required.

The preview required for the control of the lateral position is much shorter. Based on practical experience and research results, one takes usually some 5 seconds (Allen et al., 1977; Weir & McRuer, 1967). This seems adequate for most manoeuvres within the traffic lane; however, for changing lanes it seems rather short. Taking into account the range of normal low-beam headlights of some 50 - 100 m it is usually accepted that, provided the road markings are adequately visible (also in wet conditions) public lighting is not required for roads on which the driving speeds are not too high (Schreuder, 1981a, 1981b). A limit, however, cannot easily be given at present, nor the required light level (luminance level) when the vehicle lighting is not sufficient. Practical experience in the Netherlands suggests that a level of about 0.7 cd/m^2 seems to be adequate, and a level of about 0.3 - 0.4 cd/m^2 seems to be too low. This pertains to multi-lane rural motorways with a speed limit of 100 km/h. Scientific support of these values, however, is not available. Obviously, these aspects relate to what is usually called <u>visual</u>

(or optical) guidance. Recent research suggests that, at least in conditions of low traffic density and on rural roads, this aspect is equally important or even more so than the visibility of (small) objects (Walraven, 1980). Further research, particularly involving a wider range of road and traffic conditions, is still required.

One final remark. All this pertains to vehicles that carry their own lights, like low-beam headlights. Pedestrians have no lighting, so pedestrians require at night under all circumstances some public lighting in order to be able to perform their basic task. To a certain extent the same holds for pedal bicycles. This point is of great importance when the lighting of residential areas is considered (Schreuder, 1979; Caminada & Van Bommel, 1980).

As regards the second task aspect, the "coping with emergencies", the task requirements are quite different. On the one hand, one has to keep in mind that it always has to do with unexpected and unwanted situations. Thus, the reaction time should be assumed to be greater than in Task I. On the other hand, emergencies allow for emergency braking so that the minimum stopping distances are shorter.

Emergencies may require different reactions from the part of the traffic participant. The most demanding of these is, more in particular for car drivers, the manoeuvre "stopping when needed". In visibility terms, this implies that the obstacle is visible (is seen) at such a distance that the driver still can stop safely. Assuming that the retardation a is constant during the manoeuvre, the stopping distance s follow from the well-known formula

$$s = v \Delta t + \frac{v^2}{2a}$$

in which v is the speed at the beginning of the stopping manoeuvre, and Δt the so-called "reaction time". Now, this quantity Δt is in fact a composite factor. First, it includes the time interval t_1 required to detect the object. This must be multiplied by a factor m_1 which represents the need to select the relevant information, the degree in which the object is conspicuous, or the degree it stands out from the surround.

This factor m_1 also includes the influence of the arousal. Furthermore, the object needs to be recognised and localised. This requires a time interval t_2. Again a factor m_2 is needed to consider the aspects like motivation and probably fatigue and alcohol influence and finally the decision to stop must be made, and put into effect. This requires a time interval t_3 with a factor m_3 in which the complexity of the situation and the unexpectedness of the object (the pattern of expectation) plays a role. So, in total we have

$$\Delta t = t_1m_1 + t_2m_2 + t_3m_3.$$

It goes without saying that this represents only a first approximation; it is even not certain that the resulting "reaction time" can be represented in such a way by a combination of multiplications and summations. The important factor is, however, that it seems likely that all the contributing factors we have mentioned can be expressed in terms of the required stopping distance and that all of them seem to <u>increase</u> this distance.

It is difficult to quantify Δt. Obviously in real traffic it is considerably larger than the laboratory values of 0.2 and 0.3 s and even the traditional "reaction second" seems somewhat short. To be on the safe side, we will take 2 s for our further considerations, not the 5 s that have been given earlier: when considering Task I one has to take driver comfort into account and also the fact that rather complicated decisions may be involved.

The preview time (or distance) can easily be calculated if Δt and a are known. We will take for a: 5 m/s^2 for higher speeds, taking into account the fact that for high speeds, braking usually is somewhat less effective. In our example we will take three driving speeds: 15, 20 and 30 m/s, corresponding with urban traffic, driving on trunk roads and driving on motorways. The calculated preview distances are then: 55 m, 85 m and 180 m respectively (rounded off values). The first allows driving with lowbeam headlight; the second requires a "fairly good" public lighting, and the third requires "good" public lighting plus signalling lights or markers of a good quality. Obviously, the next step is to establish what is "fairly good" and "good". First, an important note should be made.

From the calculations quoted above it is quite clear that the manoeuvre "stopping" cannot be performed safely at high speeds with dipped headlights only. Having motorways without public lighting does not allow for stopping for obstacles; however, this is the standard situation - a situation that proves to be acceptable! This implies that in normal conditions there are very few reasons to stop on a motorway; this follows also directly from accident data. However, it is good to realise that this involves a (policy) decision with certain risks. The risk level of such decisions is quite clear when chain-accidents or "pile-ups" happen: the average driver does not have the slightest chance to avoid the collision!

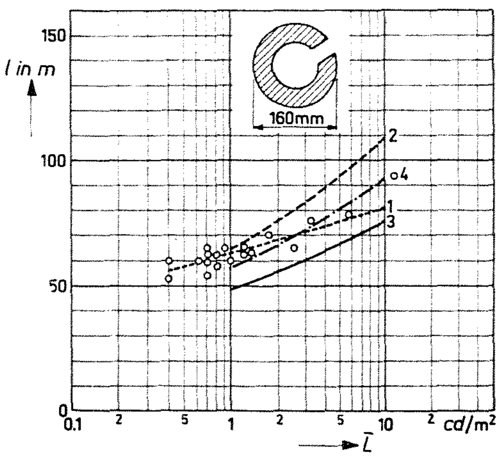
When considering the required luminance level for public lighting, our starting point will be the adaptation of the eye. It is well established that the visibility (and thus the visibility distance l) depends upon the adaptation luminance, the contrast, the size and shape of the object, and the time of observation, and also on the criterion for visibility. In experiments, usually the contrast, size and shape have been selected on an arbitrary basis with the aim of selecting something that is representative of the actual visual task in traffic. As an example, the results of a series of measurements are given in Figure 1. They pertain to a Landolt C object of 160 mm diameter and a reflection factor of about 9% (thus the contrast is not constant). The visibility criterion is 80% correct answers. The time of observation was not restricted (see De Boer, 1967). Figure 1 gives the relation between l and the average road-surface luminance, which is taken as to represent the adaptation level. For $\bar{L}$ = 1 cd/m^2, l is about 65 m. This obviously is not representative for the visibility of a truck in the street: no wonder as the visible object (the gap in the Landolt C) corresponds with some 40 mm! Still, the measurements are important, as they show firstly the large spread between the individual observation, and secondly the fact that the dependency upon $\bar{L}$ is only weak. This means that one should not expect to find a precise answer on the basis of this type of experiments regarding the minimum luminance level required for a particular type of road. This proviso is even more severe when one takes into account that the measurements were stationary without any distraction or disturbance, for unrestricted time and performed by well-trained, well-informed, highly motivated, sober and rested observers. On the basis of experiments of visibility one will not arrive at a precise value of the required light level for road lighting.

We discussed only the light level in terms of the road-surface luminance. Obviously the results depend upon the non-uniformity of the luminance pattern and the glare. The influence on the visibility is considered, however, to be small of compared with the influence of the luminance.

Class	Traffic volume		
	High	Medium	Low*)
Motorways			
Primary roads			
with bicycles			
without bicycles			
Secondary roads			
high % through traffic*)			
low % through traffic*)			
Residential roads			
high % through traffic*)			
medium % through traffic*)			
low % through traffic*)			

*) Taking into account the type of road

Table I. Classification of roads



Distance l at which the gap in 80% of the Landolt rings presented was seen correctly, as a function of the average road surface luminance $\bar{L}$.
1 – results of measurements, carried out partly in open-air laboratory and partly in normal road-lighting installations.
2 – calculated according to Balder and Fortuin for observers aged between 15 and 24.
3 – calculated according to Balder and Fortuin for observers aged between 55 and 64.
4 – calculated according to Balder and Fortuin for observers aged between 15 and 64.

Figure 1 (after De Boer, 1967)

REFERENCES

Allen, R.W. et al. (1977). Drivers' visibility requirements for roadway delineation, Vol I. Report FHWA-RD-77-165. STI, Hawthorne, Cal., 1977.

Anon (1963). Research on road safety. HMSO, 1963.

Box, P.C. (1956). Relighting Kansas City, Missouri. The American City, 1956, March, April, May, June.

Box, P.C. (1970). Roadway lighting. Proceedings Highway Safety Conference, pp. 87-96. Virginia Polytechnic Inst., Balcksburg, Virg., 1970.

Box, P.C. (1972). Freeway accidents and illumination. Highway Res. Rec. No. 416, pp. 10-20. HRB, 1972.

Brühning, E. & Weissbrodt, G. (1981). Wirksamheit von Massnahmen gegen Nachtunfälle. Strassenverkehrstechnik 25 (1981) 1-7.

BSI (1952). Street lighting lanterns. British Standards Institution, London, 1952.

Caminada, J.F. & Van Bommel, W.J.M. (1980). New lighting considerations for residential areas. Int. Lighting Rev. 31 (1980) 69-75.

CBS (1984). Statistiek van de verkeersongevallen op de openbare weg 1982. (Statistics of road-traffic accidents). Staatsuitgeverij, Den Haag, 1984.

CIE (1960). Street lighting and accidents. Publication No. 8. CIE, Paris, 1960.

CIE (1980). Proceedings 19th Session, Kyoto 1979. Publication No. 50. CIE, Paris, 1980.

CIE (1983). Road lighting and accidents (5th draft). Publication No. 8-2 (in preparation) CIE, Paris, 1983.

Cornwell, P.R. & Mackay, G.M. (1972). Lighting and road traffic I: Public lighting and road accidents. Traffic Engng. & Control 14 (1972) 142-144.

De Boer, J.B. (1967). Chapter II in: De Boer, J.B. (ed.) (1967).

De Boer, J.B. (ed.) (1967). Public lighting. Centrex, Eindhoven, 1967.

Fisher, A.J. (1977). Road lighting as an accident countermeasure. Austr. Road Res. 7 (1977) 4: 3-16.

Hargroves, R.A. & Scott, P.P. (1979). Measurements of road lighting and accidents; The results. Public Lighting 44 (1979) 213-221.

Janoff, M.S.; Koth, B.; McCunney, W.; Freedman, M.; Duerk, C. & Berkovitz, M. (1977). Effectiveness of highway arterial lighting. Final report No. 7737. Franklin Institute, Philadelphia, Pa., 1977.

OECD (1971). Lighting, visibility and accidents. OECD, Paris, 1971.

OECD (1980). Improving road safety at night. OECD, Paris, 1980.

Schreuder, D.A. (1979). The lighting of residential yards. R-79-49. SWOV, 1979. Also in: CIE (1980).

Schreuder, D.A. (1980). Verlichting voor het verkeer (Traffic lighting). R-80-4. SWOV, 1980.

Schreuder, D.A. (1981a). Profilierte Fahrbahnmarkierungen. Bibliographien über Einzelgebiete des Strassenbaues und der Verkehrstechnik Nr. 43. Forschungsgesellschaft für Strassen- und Verkehrswesen, Köln, 1981.

Schreuder, D.A. (1981b). Visibility of road markings on wet road surfaces; A literature study. Study Centre for Road Construction SCW, Arnhem, 1981.

Schreuder, D.A. (1983). De relatie tussen verkeersongevallen en openbare verlichting. (The relation between traffic accidents and public lighting). R-83-12. SWOV, 1983.

Scott, P.P. (1980). The relationship between road lighting quality and accident frequency. LR 929. TRRL, Crowthorne, 1980.

Sielsky, M.C. (1967). Relationship of roadway lighting and traffic accidents. HRB Spec. Rep. No. 93, pp. 172-177. HRB, 1967.

Skene, P. (1976). The cost-effectiveness of upgrading urban streetlighting. University of NSW, 1976.

Thorpe, J.P. (1963). Traffic accident measurements. Journ. Inst. Engngs. (Aust) 35 (1963) 3: 31.

Turner, H.J. (1962). The influence of road lighting on traffic safety and service. Proc. ARRB 1 (1962) 1: 596-618.

Walraven, J. (1980). Visually critical elements in night driving: A pilot study (In Dutch). Report C-22. IZF-TNO, Soesterberg, 1980.

Walthert, R. & Hehlen, P. (1980). Strassenbeleuchtung - mehr Sicherheit, ein Handbuch für Gemeindebehörden. BFU-Schriftenreihe Band 13. BFU, Bern, 1980.

Weir, D.H. & McRuer, D.T. (1967). Conceptualization of overtaking and passing manoeuvres on two-lane rural roads; Volume III. Technical Report No. 1-193. STI, Hawthorne, Cal., 1967.

Zuman, N. (1980). The case for improved street lighting. The Highway Engineer (1980) Feb.: 8-11.