THE RELATIONSHIP BETWEEN THE LEVEL OF STREET LIGHTING AND THE TRAFFIC SAFETY

A preliminary study

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Dr. D.A. Schreuder
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SWOV Institute for Road Safety Research, The Netherlands

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FOREWORD

Road lighting represents only a relatively small post on the expenditure, both regarding costs and energy. Nevertheless, it involves considerable sums, and it seems to be justified to use the money and the energy for road lighting as good as possible, particularly in times where public expend- iture and energy consumption are carefully considered.

In 1981 the Ministry of Economic Affairs of the Netherlands issued a brochure to help local authorities to be more effective with the public lighting (SVEN, 1981). The aim was to reduce the operating costs of public lighting without harm to the quality regarding road safety and public security. This brochure was set up by the Ministries of Economic Affairs and of Transport, with the participation of the Dutch Illuminating Engineering Society (NSvV). The brochure was widely distributed, and also widely used.

The data on which the brochure, as well as the recommendations it contained are based, need to be updated. There was some difference of opinion how to do this. Furthermore, the NSvV made a start to revise its own recommendations for road lighting, that dated from 1974 (See De Man, 1989). It was generally felt that new research was needed. For this research a Steering Group was set up, consisting of the Ministries mentioned above, and the NSvV.

The research focusses on urban streets and roads. At the same time, the Ministry of Transport initiated a similar research programme for rural main roads. Careful planning of this research is needed to avoid "double work".

The effectiveness of road lighting is a wide area of research. Therefore, the actual research is preceded by a preliminary study, which was contracted to SWOV. The results of this preliminary study are presented in this report, which is a full translation from the Dutch of: "De relatie tussen het niveau van de openbare verlichting en de verkeersveiligheid; Een voorstudie". R-89-45. SWOV, Leidschendam, 1989. (Schreuder, 1989).

1. INTRODUCTION

1.1. Set-up of the study

The preliminary study consists of three parts:
1. a report of the "state of the art";
2. a survey of the energy saving measures taken to date;
3. a pilot study.

1.2. Additional literature survey

In 1983, SWOV published a literature survey on the relationship between road lighting and traffic safety (Schreuder, 1983). This study concluded that "on major urban thoroughfares, good road lighting results in a reduction of about 30% of the nighttime casualties. Furthermore it seems that a similar effect is to be expected on rural trunk roads and motorways".

This conclusion concurs with earlier studies. The 1983 study obviously includes earlier surveys, but it also included new material that was not published earlier. As all data lead to the same conclusion, it is justified to speak of a well-established fact. Also the Commission Internationale de l'Eclairage gives the same statement in its forthcoming survey.

The 1983 study left a number of questions unanswered:
- which roads require road lighting?
- how good is "good"?
- what is the accident reduction - if any - on other types of road?
- may one expect a similar relationship for the other functional aspects of road lighting (throughput, public security, amenity)?

The first part of the preliminary study was to update the 1983 literature survey. This additional literature study should concentrate on the question how good is "good". For this, it is necessary to know the quantified relationship between the level of lighting (quality or quantity) and the road safety. This additional literature survey has been published (Schreuder, 1988).

The 1988 study pointed out that it is not yet possible to give this relationship. The research into this matter was either to small, or too specialized. This was more in particular the case for the large UK study. The UK study suggests that the relative frequency of nighttime injury accidents diminishes for increasing luminance level. As a result of the small number of roads, and therefore of accidents involved in this study, it was not possible to come to a more explicit conclusion. The small sample was a result of the fact that the measurements of the lighting condition were very elaborate - in fact much more elaborate than necessary.

1.3. Energy-saving measures

The second part of the preliminary study consisted of a survey of the energy-saving measures that had been taken to date. The degree to which the brochure of SVEN was known and used, was a part of this study.

The study was made by the "buro voor industrieel en professioneel onderzoek INDIS" (The bureau for industrial and professional research INDIS). The results have been published.

The study gives a survey of the practice of road lighting in the Netherlands. It was shown that in the period between 1981 and 1986 the same amount of energy was used, but that the length of the lit road network had increased slightly.
Furthermore, it was shown that the majority of the municipalities tries to reduce the energy consumption for street lighting, but that it proved to be too difficult to bring this into effect, particularly as adequate, simple and to-the-point recommendations are not available.
Thirdly, it was found that the brochure that was published by the Ministry of Economic Affairs was used on a wide scale by the municipalities. A quantification could, however, not be given.

Regarding <u>energy policy</u> the following conclusions were drawn:

- There seems to be some - but not a large - room for further savings as regards energy consumption for public lighting, taking into account that the quality needs to be maintained.
- Further research is needed to specify the measures, particularly as regards the relevant light levels.

- There is an urgent need for relevant, to-the-point and simple recommendations.

Regarding road safety policy it seems that there is some room to reduce energy consumption while maintaining the road safety level.

Regarding crime prevention policy it is clear that there is a serious lack in "hard" data on the relation between public lighting and crime. Further studies are needed.

1.4. Conclusions

The conclusions from the first two parts of the preliminary study supported the recommendation to undertake the third part of it as well.
This third part is a pilot study with the following objectives:

- Is it in principle possible to answer the question?
- Can the proposed method be used?
- What will be the dimension (costs) of a full scale investigation? Are additional data required for the set-up of such an investigation?

2. THE ACCIDENT STUDY

2.1. Introduction

The pilot study (the third part of the preliminary study) is an accident study; more specific, it as a relation study. The number (and the severity) of accidents are related to other aspects of the traffic and transportation system - in this case primarily the public lighting. The advantages and the disadvantages of accident studies are well-known: the main advantage is that the result gives directly the required relation: road safety is expressed in accidents. The main disadvantage is the "statistical" nature of the study. Information on the underlying causal relationships can be found only indirectly; these causal relationships are essential to find effective accident counter measures. However, accident studies are needed to "calibrate" the studies that are focussed on these causal aspects. Research on both areas is under way.

2.2. Set-up

The study is based on the assumption that the accident risk diminishes when the lighting level increases. This assumption is based on practical experience and on theoretical considerations. The experience is the result of earlier research that showed that road lighting is an effective accident countermeasure. The theoretical considerations are based on the fact that visual performance increases with increasing light level (adaptation level).

This assumption can be elaborated upon. When one plots the accident risk in the dark (e.g. the ratio between the night and day accident numbers n/d) to the light level (e.g. expressed in the horizontal illumination E_{hor}) according to the assumption one should expect a curve of the shape as depicted in Figure 1. The curve does not begin at light level zero, as vehicles always carry head lamps, that give some, be it a low, level of illumination. With increasing light level, the n/d ratio decreases as a result of the considerations given earlier. However, this decrease does not continue to n/d=0 but it levels off at a level of n/d > 0, because also at day accidents that are related to visual aspects occur. This is a major reason for introducing the "daytime running lights". After the "asymptote" is reached, the curve continues in a horizontal fashion.

The pilot study is a relation study: the study deals with the relation between the following aspects:
- accident characteristics
- lighting characteristics
- road characteristics
- traffic and transport characteristics.

The pilot study is based on a simple set-up. The relationship between the accidents and the lighting characteristics were investigated, whereas the other aspects were regarded as "parameters". In case the pilot study proves this to be insufficient, it may be necessary to select a more elaborate method of analysis for the full scale investigation.

The set-up selected here was influenced by the large British study that was mentioned before. The British study was based on an accurate and comprehensive assessment of all lighting parameters. This resulted in about only 70 streets to be included in the study. Therefore, only a small number of accidents was available; as a result, the statistical spread was large. Accurate traffic data were not available. Consequently, the traffic aspects were deleted from the study. This set-up resulted in a limited number of useful data, although the (organizational and financial) effort was large. This study is summarized to some detail in the earlier studies of SWOV (Schreuder, 1983, 1988).

For our pilot study, we chose a different approach, as it seemed that unnecessary refinements led to this limited result. The main objective was to secure a large "sample" of accidents; because the financial resources were very limited, the other data could be gathered only in general terms. From this resulted the need to restrict the research to small "areas", both in the geographical and in the organizational sense. In a small area usually one, or only a few, persons can collect all the relevant data in a simple way (often they have it all in their memory!). It is necessary to ascertain that data from different areas can be combined.

The pilot study was made in three towns in the Netherlands: Leeuwarden, Amsterdam-West and Utrecht. The data from Utrecht were delayed. The report is based on the data from Leeuwarden and Amsterdam-West.

2.3. Required data

2.3.1. Accident data

The road safety is characterized by the number of accidents. Usually, the accidents are subdivided according to their seriousness (fatal accidents, injury accidents, damage-only accidents), according to the road authority (national roads, provincial roads, municipal roads) and according to the mode of traffic participation (pedestrian, cyclist, driver, passenger etc). This is needed as on a national basis the registration of all these classes of accidents may be quite different. The difference as regards the registration between municipalities, day and night, road type and authority, and traffic participation as well established. In our study we could use all accidents, because we only compare the lighting conditions in the same streets within the same municipalities, and at the same time. It is difficult to think of large differences in registration for streets of a single type, in a single town and at a specific time.

It seems logical to try and to use the data collected by the national Road Accident Records Office (Dienst Verkeersongevallenregistratie VOR). For this, we used a special programme developed by SWOV. In view of the large "black numbers" this system employs fatal and serious injury accidents only. VOR splits up all accidents into intersection accidents and "in block" road accidents. So it is from the VOR-data not possible to establish to which road the intersection accidents "belong". For Leeuwarden, this was established by hand for each accident individually, using additional data from the municipality, a city map and the accident data collected by the Province. For Leeuwarden the intersection accidents amounted to about 70. Even this small number took many hours to analyze. It was concluded that the (national) VOR-data could not be used, as the number was far too small and the processing time far too large.

Consequently, we had to use police data. In principle, this is very simple: the police keeps a copy (the "green") of the registration form. All relevant data are quoted. It turned out to be very difficult to get the actual data: first, most municipalities do not have the data filed on a computer so that all data had to be processed by hand. Secondly, the privacy of citizens is jealously guarded, and finally, the police forces suffer under serious shortages of personnel. It proved impossible to have the data processed by the police themselves. Attempts to do so did delay the study for almost two years. In the long run, the data proved to be adequate.

2.3.2. Lighting data

The lighting is characterized by the average horizontal illumination E_{hor} on the plane of the road surface. Obviously, E_{hor} is not more than an approximation of the quantity that determines the visual perception in streets and on roads. The road-surface luminance is important; this determines the state of adaptation of the visual system, which governs finally the possibilities for visual perception. More in particular in the luminance regions relevant for nighttime road traffic, the visual perception depends heavily on the state of adaptation. At the other hand, the perception - more in particular the recognition - of objects in the road can be characterized much better by the semi-cylindrical (or by the vertical or by the hemispherical) illumination than by the average road-surface luminance. Still, we selected E_{hor} because it is not possible to assess the other characteristics in a simple (cheap) way for a large number of streets, and because one might expect a considerable degree of correlation between all these characteristics, particularly for the streetlighting installations that are common in the Netherlands.

Still, there are a number of problems concerning E_{hor}: what should be taken as the measuring area, and how many measuring points are required? We preferred to use the average value of E_{hor} on the road surface (the carriage-way) in spite of the fact that side-walks and cycle-tracks are often equally important (particularly in the Netherlands). Most measurements were made with nine measuring points, but also sometimes with only two or three. In these cases, the data needed to be corrected.

Both for Leeuwarden and for Amsterdam-West the lighting data for all streets were provided. These data are collected in different fashion. Partly they are measured directly; partly they are assessed on the base of analogy with well-known streets, and partly they are calculated on the basis of the geometry of the installation, and the types of lamp and lantern. This means that the accuracy of the light level is not too good, that it is n precisely known, and that it is not the same in all cases. This seems, wever, not to be critical, particularly as the results of the investigations suggest only a weak relationship between the light level and the accidents - if any at all. For a weak relationship an accurate assessment of E_{hor} is not required. However, for a large-scale experiment a more precise assessment of the light level is necessary. It should also be considered to include the degree of non-uniformity (in E and/of in L) as well.

The data were collected just for this study; although one could have it to be otherwise, it turned out that no-one made ever such inventories of the lighting data before!

2.3.3. Traffic data

The characteristics of the road and of the traffic can be only assessed if a classification of roads is available. Until recently, classifications of roads that could be used for road lighting and road safety research were not available.

More recently, the NSvV set up a classification system for roads as a part of the revision of their Recommendations for Road and Street Lighting. This classification is based on the following four entries:
- place of the road in the road network (through traffic etc.)
- function of the road (traffic and/or residential etc)
- traffic intensity
- infrastructure (cross section etc).

All entries relate to data that can be observed (measured) directly from the road itself. The classification includes well over 100 classes, and is not applicable for the research described here. We were able, however, to design a simplified classification that is based on the same principles as the NSvV-classification. This classification shows seven classes (plus an eighth class for squares, parking lots etc). The classification is given in Figure 2.

The classes from 1 to 7 from this classification can be regarded as an ordinal scale of the degree of "importance" of the roads; assuming that the traffic in class 4 generally is higher than that in class 5, it can even be regarded as an ordinal scale of traffic intensity. We will use the classification in this fashion (see Chapter 5).

One problem of this type of classifications is the likelihood that the characteristics will show some sort of interaction, more in particular the data on the lighting, the type of road and the night/day ratio of accidents. It is well known that when designing road lighting, and more in particular in setting up the functional specifications, authorities usually take into account the degree in which a particular road is "dangerous" in the dark - even if it is not possible to specify the "danger" in more precise terms. It is not possible to predict in how far, and in which way, the results may be influenced. But practice often shows a clear relation between the light level and the "importance" or the "danger" of a road.

There is another problem. There might be a difference in interpretation of the same class of road in different towns. In the present study this question is not further pursued, if only because we have clustered the classes even further. It is, however, a matter to consider for a large scale investigation, particularly when an international study is planned. One way out is to assess the traffic intensity (by means of traffic counts) in an objective way, and to "calibrate" the subjective ratings according to the traffic counts for these roads.

Both for Leeuwarden and for Amsterdam-West information is provided for all roads regarding the type of road and the traffic. The summary version of the NSvV-classification is used. The results suggest that the classification is not detailed enough to allow for all the relevant details in the characteristics of the roads. We will come back on this matter in Chapter 3. At the other hand is turned out that, taking into account the dimension of the pilot study, the classification was too detailed to ensure enough data in each cell.

2.4. Results

2.4.1. Results from Leeuwarden according the VOR-data

All VOR casualty accidents from Leeuwarden for 1986 have been analyzed. The total number was 305 accidents, subdivided in day and night (actually daylight and darkness including twilight), and in intersection accidents and mid-block accidents.

	mid-block	intersections	total
daylight	49	168	217
darkness	24	64	88
total	73	232	305
% darkness	32,9	27,6	

In view of the small numbers the data are not subdivided according to the type of road. In Table 1, the results are subdivided according to the lighting.

Table 1 gives the data of the analysis. The percentage of accidents by darkness (twilight included) of the total is given, and so is the ratio between the accidents by darkness (n) and by day (d). The ratio (n/d) is often used because in this way, at least in part, the influence of disturbances (traffic, road length, weather, changes in car population etc.) can be corrected for. The data are given for the lux values, and also according to the classes in illumination that will be used further-on. These classifications are selected on pragmatic grounds. The results are given in Figure 3.

2.4.2. Results from the police data

The accident data provided by the police for Leeuwarden and Amsterdam-West are given in Tables 2 and 3 respectively. These data are derived from the accident forms (the "greens") as used by the police. Some of the data from Leeuwarden are corrected for the illumination and for class of road. As was to be expected, not all classes of roads, nor all classes of illumination are represented equally strong. In this way one might find some differences in the "lighting culture" of the two cities. These differences do not seem to be important for the combination of the data from two towns. The combined data are given in Table 4.

The total number of accidents in this study seems to be quite large (nearly 9000, from which about 2000 night accidents). Nevertheless, many cells are almost or completely empty. There seems to be a clear relation between the "importance" of the road and the illumination: more important roads usually have a higher illumination. As such, we should not be surprised: it is a logical outcome of the lighting policy of many local authorities who are responsible for road and street lighting. Still, it might complicate things for an accident study.

The empty cells prompted to take groups of roads and of lighting together. For the roads, we used two different clusterings (both based on the NSvV - classification of roads). The first clustering focusses on the traffic intensity, the second on the function of the road. The clusters are given in Table 5. This clustering obviously is not optimal, as we already indicated that the classification of Figure 2 was in some respects not fine enough. For a full scale investigation it seems to be necessary to keep at least the original classification of Figure 2, and preferably an even finer one.

The illumination has been clustered as well. As we indicated already, this clustering is based on pragmatic considerations. Two clusterings have been used:

* <5; 6-9; 11-15; 16-20; >20 (lux)
* 1-3; 4-6; 7-9; 10-12; 13-15; 16-17; 18-19; >20 (lux).

In Tables 6 and 7 the data from Leeuwarden and Amsterdam-West are combined, where the different clusterings have been used. In these tables the data from the cells that were nearly empty have been omitted. The criterion was: less than 10 night accidents (nominator of the n/d ratio smaller than 10). The data are given as well in Figures 4 and 5, and Figures 6 and 7 respectively.

3. DISCUSSION

3.1. Hypothesis

In Sec. 2.2 we indicated already that this research is based on the hypothesis that when the light level increases, the risk for nighttime accidents decreases. This would imply that according Figure 1 the n/d ratio would, for increasing E_{hor}, decrease first, and would reach an asymptote afterwards.

The results of the pilot study cannot, however, be regarded as a confirmation of this hypothesis; on the contrary, there does not seem to be any relation at all between the light level and the road safety. We will discuss these results more in detail.

3.2. Relationships

Usually, one assumes that there is a simple relation between the light level and the road safety. As a matter of fact, this assumption is the combination of three distinct assumptions:

1. There is a one-to-one, monotonous relation between the horizontal illumination on the road surface, and the state of adaptation.
2. There is a similar relationship between the state of adaptation and the visual performance.
3. And finally, a similar relationship exists between the visual performance and the road safety.

Only when all three relations are monotonous, the combination can be monotonous as well.

The three assumptions are plausible; on the basis of what we know about the psychophysics of the visual system it is very unlikely indeed that the relationships would be the other way around. There is, however, a considerable amount of doubt as to in which way these relationships work out in practice.

The first relation (between the illumination and the state of adaptation) is far from secure. In roads with public lighting installations, there is no clear-cut relation between the illumination on the road and the road surface luminance. Furthermore, the road surface is only a minor part of the field of view, so that the state of adaptation (and sometimes in a major fashion) will be determined by the luminances in other parts of the field of view. First of all, the luminaires of the street lighting cause glare. Even in roads that fulfill the requirements of CIE or NSvV regarding "discomfort glare", the state of adaptation may some 10 to 20% higher than would agree with the road surface luminance (as is quantified by the permitted values of the threshold increment TI). It is well known that also in the Netherlands, many streets do not comply with the CIE or the NSvV recommendations, notably residential streets. When opposing traffic with low-beam headlamps occur, the state of adaptation will increase considerably. Even on well lit roads one car with well-adjusted low beams may easily double the state of adaptation. It should be noted that these considerations are not a result of direct measurements. They are based on the increase on the threshold of perception as a result of the glare; they are only a - rather accurate - approximation. And finally other light sources (show windows, offices, homes, sport stadiums etc.) may have a considerable influence on the state of adaptation. In conclusion, it is not likely that the sate of adaptation always will follow a simple, monotonous one-to-one relationship with the illumination on the road surface.

The second relation (between the state of adaptation and the visual performance) is well established in literature. It is well-known that the visual performance increases with increasing state of adaptation. Research in the "mesopic" area did show that this relation is particularly important is the area of luminances that are relevant for nighttime road traffic, the subject of this study.

Regarding the third relation (between the visual performance and the road safety) only little research has been made. It is generally assumed that the relation exists, and even more, that it is a "strong" relation. This assumption seems to follow common sense: "It is necessarily so: obviously one cannot drive a car when one cannot see properly". However, some further consideration shows that this relation is not "obvious" at all. Accident data show clearly that accident risk is considerably higher in the dark, in poor visibility or in poor weather as compared to daylight, and clear and dry weather. But even so the accident rates are still extremely low in an absolute sense: the probability to come home safely is still many tens of thousands higher that the probability to have an accident. Furthermore, people who have a long-term visual handicap may compensate for it. This compensation usually is so strong that one might find hardly any relationship between the visual performance of individual drivers and their accident involvement. This leads directly to the second assumption with a more "scientific" character. It has been shown that far out the largest part of the information required for the driving task (often one puts the estimation at 95% or even more) is visual information. In this sense, the visual information is essential for driving. This does not imply at all that there should be a strong relation between the quality (or quantity) of the visual information and the quality of traffic participation (and this is definitely not equal to being involved in few accidents); in the contrary. Recent research did suggest that accident more often result from erroneous decisions than from faulty perception: the cognitive aspects of the driving task are much more important than the perceptive aspects.

In conclusion, it seems that the second assumption is well-established, but that the first and the third assumption cannot be supported at present by research. This implies that it not possible to predict the shape of the relationship. One might expect a simple, monotonous increasing relationship, but it might be quite possible that the increase is so small that it cannot be found in a simple pilot experiment. For a more secure establishment of the relationship between the n/d ratio and E_{hor} a more comprehensive study is required.

3.3. Interactions

Matters turn out to be even more complicated as a result of the interactions that are likely to exist between the "danger" of the road and the light level that will be selected for that road. In general terms, the interaction is quite pronounced; as a matter of fact, this interaction is the underlying idea for all traditional recommendations for road lighting. Road with heavier traffic are more "dangerous" than roads with little traffic; high-speed roads are more "dangerous" than low-speed roads, and are consequently installed with a higher light level. A similar interaction might be expected to exist as well for individual roads. This interaction results in a more "horizontal" shape of the curve in Figure 1. When the interaction was perfect - the goal for road-lighting policy in many towns! - the curve would degenerate in a horizontal, straight line.

The fact that there is hardly any relationship between the n/d ratio and E_{hor} need not imply that the hypothesis is wrong. It is quite possible that the relationship is "hidden" in de the interaction.

It might be possible to reduce the influence of this interaction by selecting another "control group". Presently, we used daytime accidents as a control. One could select for both the study group as for the control group nighttime accidents. In towns that use a two-level switching (an "evening" regime and a "night" regime) the ratio between evening and night accidents could be used. On a small scale this is has been done in a study in the town of Dordrecht (Schreuder, 1985). In that study a reduction in the night/evening ratio with increasing light level was found, whereas the night/day ratio and the before/after ratio did not show any clear dependency. A draw-back is that this system can be used only in towns that use a two-level lighting installation. Another way is to compare "relevant" and "non-relevant" accidents. This implies accidents where some influence of the road lighting might be expected, versus accidents that cannot be influenced by (the level of) the road lighting - or two types of accidents that are influenced by lighting in a different way. It was suggested to use multi-vehicle accidents and single accidents respectively. Further research is required before a sensible selection of types of accidents can be made. An obvious draw-back would be that one needs more data for each accident.

3.4. The results

The hypothesis is not supported in a simple way by the results of the pilot study. The hypothesis, however, seems to be rather well-founded (Sec. 3.2 and 3.3). It might be possible that all results correspond to the asymptote of Figure 1: the region where a further increase in the lighting level does not result in a (further) decrease in accidents. In view of the low light levels that occurred in the study this seems to be unlikely, however. As it is difficult to find a better answer, we will adhere for the time being to this point of view.

The consequence of this is that the streets that are used for the preliminary study all (or at least most) are above the "knee" in the curve of Figure 1; and therefore are not below the level that is the minimum for road safety considerations. This would imply that there are most probably some streets where the light level could be reduced. One should keep in mind, however, that this is a pilot study only; the set-up is far too limited to come to practical recommendations, like the possible reduction of the light level in some specific streets.

In Chapter 5 we will indicate how a research programme should be designed that allows the drawing of such conclusions. However, there seems to be some room for some further energy saving for the lighting in view of the road safety requirements. It remains to be seen in how far a further reduction of the light level could be justified for other considerations, more in particular regarding the public safety (crime prevention) and the amenity.

4. CONCLUSIONS

In Sec. 1.4 three questions were stated for which the preliminary study was supposed to find an answer.

The first question was about the possibilities for research. This question can be answered positively without doubt.

The second question regarded the method that was employed. As far as certain precautions are taken, this method can be used as well in a larger study:

- The method results easily in the required very large sample. It is not possible, however, to expect that the different police forces can cooperate without any compensation.
- The classification of roads needs to be more detailed.
- In order to have the required accuracy, the scale of the study must be considerably larger.
- For the time being, the rather crude way to assess the light level seems to be adequate. A more comprehensive study, however, requires a more precise assessment of the light level.
- In all likelihood, the interaction between the "danger" of the road and the selected light level will complicate the drawing of clear conclusions on the relationship between accidents and the light level.
- There was found hardly any tendency that the nighttime accident risk goes down with increasing light level. A strong relationship, such as is predicted by some theoretical studies, is not found. One of the more likely causes is that even the lowest light levels that occurred in the study, already ensure a reasonable degree of road safety. A more accurate conclusion, and particularly a more accurate determination of the lowest light level for residential streets that is required from the point of view of the road safety, requires a larger study, where also much lower light levels are included. It seems possible to find such streets in the Netherlands. It should be considered, however, to supplement the data with data from cities abroad, particularly from countries that are "poorly" lit, like France or the Federal Republic of Germany.

The third question is related to the dimensions of the full scale investigation. It is difficult to answer this question in general terms. When one requires, however, that all "cells" (particularly for main thoroughfares and for residential streets) are filled with enough data to allow a careful statistical analysis, each cell should include at least 40 units. The dimension of the study should be increased with at least a factor of 10.

In the pilot study, several cells are almost empty. However, other cells are full enough, so it could be considered to increase the efficiency of the study by selecting the roads (the cells), particularly main thoroughfares with low light levels, and residential streets with high levels. In this way, the dimension of the full scale investigation could be limited to about five times the dimension of the pilot study. A careful design is essential.

5. FOLLOW-UP STUDIES

The preliminary study suggests that in some streets the light level could be reduced without endangering the road safety. Solid recommendations require further studies, that will be explained by means of Table 4.

Table 4 gives the combined number of accidents for Leeuwarden and Amsterdam-West. The data are not yet combined. The results seem to be concentrated in a restricted area of the table, around the diagonal running from "down-left" to "top-right". This area includes mainly the thoroughfares with high light levels and residential streets with low light levels. This is no surprise; as we have explained, this is what one should expect from the road lighting policy in towns. The area is a rather broad band in the table. This means that each class of roads includes individual streets with a relatively high, and other with a relatively low light level. We have pointed out already that the lowest of these levels falls outside the "danger zone" as regards road safety, a compliment for the authorities in these cities who are responsible for the road lighting policy.

This area suggests a way to establish a method for (justified) energy savings. For this, the area is subdivided in three bands, each representing one-third of the streets. One band includes the streets with the highest light levels, another the lowest, and the third the light levels with a tendency for the average. One might expect that the streets with light levels in the highest third could be selected for a reduction in light level. The reduction could be a small one, but in view of the large numbers of streets, the energy saving could still be considerable.

For this method, it is essential that the data from Table 4 can be regarded as being representative for the Netherlands. This implies that the data should come from a considerable number of towns. One could expect that one would need some tens of towns, although the exact number cannot be stated without further study. However, it is not necessary to include the complete road network of all these towns in the study, as has been done with Leeuwarden and Amsterdam-West. We indicated already in Chapter 4, that with a well-designed selection of roads (i.e. a well-stratified selection), the dimension of the study needs to be only five times as large as the pilot study. A study of this type would at the same time provide the data that are needed to investigate the part of the curve of Figure 1 below the "knee"; this would yield data regarding the minimal light level from the point of view of the road safety.

6. SUGGESTIONS FOR FURTHER STUDY

The study reported here is explicitly indicated as a preliminary study. This study has three parts, the third being the pilot study.

These studies show clearly that the method of research is applicable. Therefore we recommend to pursue a full scale follow-up research programme, such as was described in the preceding sections.

It should be pointed out, however. that several important aspects have not yet been dealt with:

- The relationship between the light level and the crime prevention. In the SVEN-brochure, issued by the Ministry of Economic Affairs, it was stated explicitly that the aim was to reduce the operating costs of street lighting installations without harming the road safety nor the public security. Some research has been done regarding the relation between the light level and the "objective" crime (the number of criminal acts), but this research needs to be extended. This could easily be combined with a study in road safety, as the two involve for a large part the same data.
- The relationship between the light level and the amenity. This would include for a large part the experience of being and feeling secure in the residential surroundings for inhabitants, notably the cyclists and the elder pedestrians. In this area there is hardly done any research, but the interest for it has been aroused by the work of the Parliamentary Commission in this field (the Commission Roethof).
- The relation between the light level and the environmental load, in which the use of electric energy is essential. In this respect a considerable amount of research has been done, but there is virtually no knowledge regarding optimising safety and energy consumption; integrated cost/-effectiveness assessments have not yet been made. Also in this respect, research data are required. The research needed to acquire these data is similar to the research related to road safety, public security and amenity, so that is seems to be fairly easy to combine these research objectives in one integrated research project.

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FIGURES 1-7

Figure 1. The relation between "danger" and light level.

Figure 2. The relation between the night/day accident ratio and the light level (Leeuwarden, 1986; based on VOR-data).

Figure 3. The night/day accident ratio for different classes of road and light levels (Amsterdam-West and Leeuwarden).

Figure 4. The night/day accident ratio for different classes of road and light levels (Amsterdam-West and Leeuwarden).

Figure 5. The night/day accident ratio for different classes of road and light levels (Amsterdam-West and Leeuwarden).

Figure 6. The night/day accident ratio for different classes of road and light levels (Amsterdam-West and Leeuwarden).

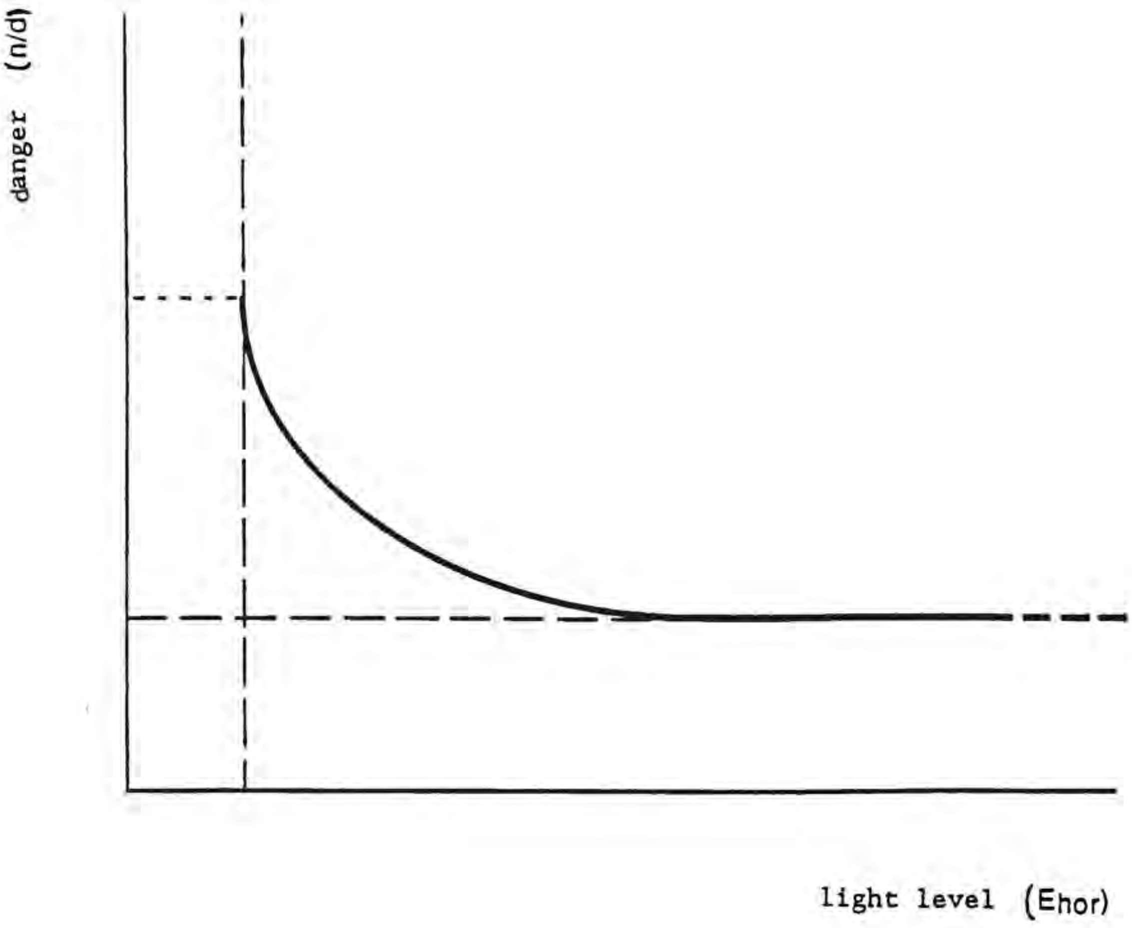
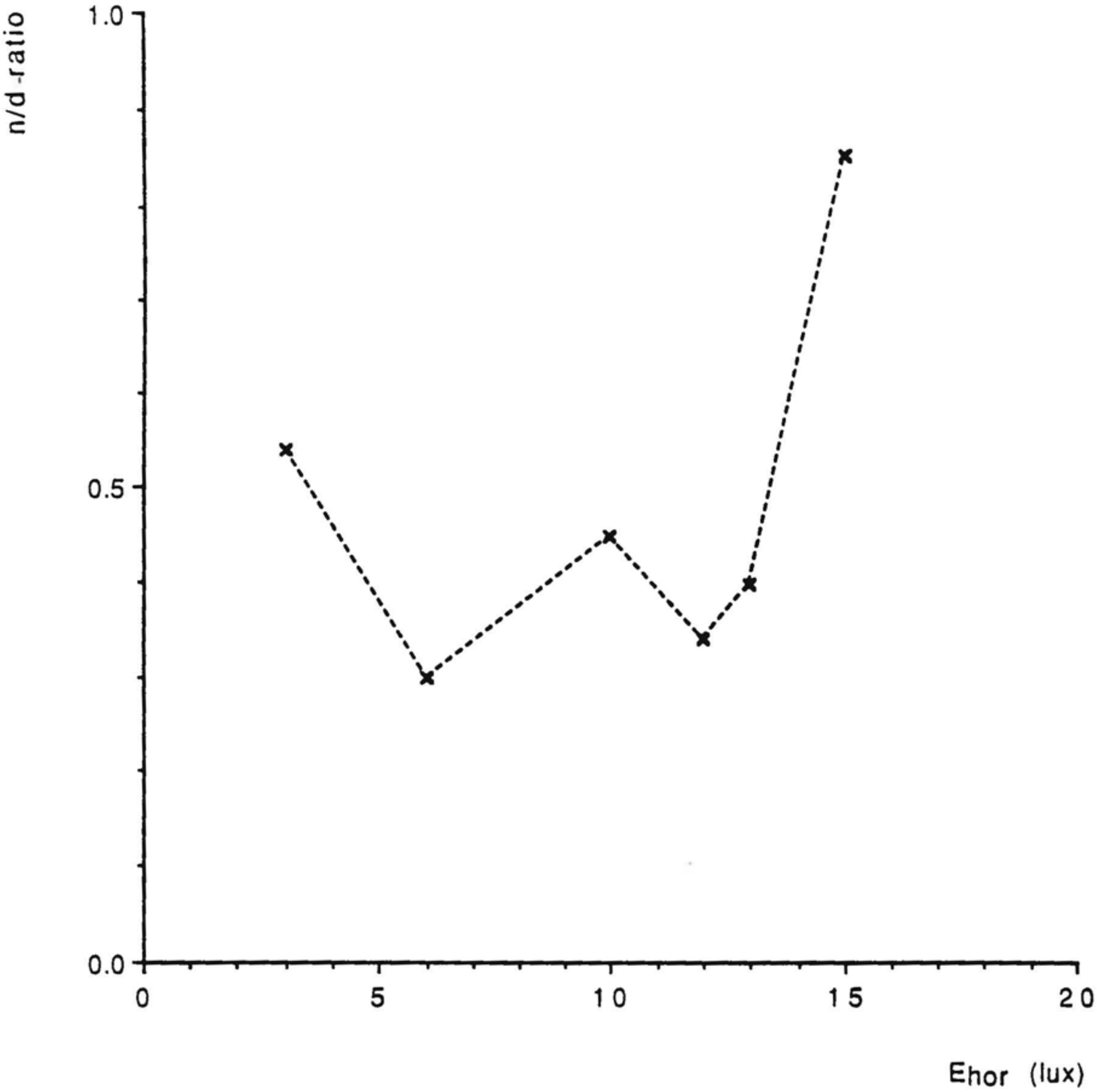


Figure 1. The relation between "danger" and light level.



<u>Figure 2</u>. The relation between the night/day accident ratio and the light level (Leeuwarden, 1986; based on VOR-data).

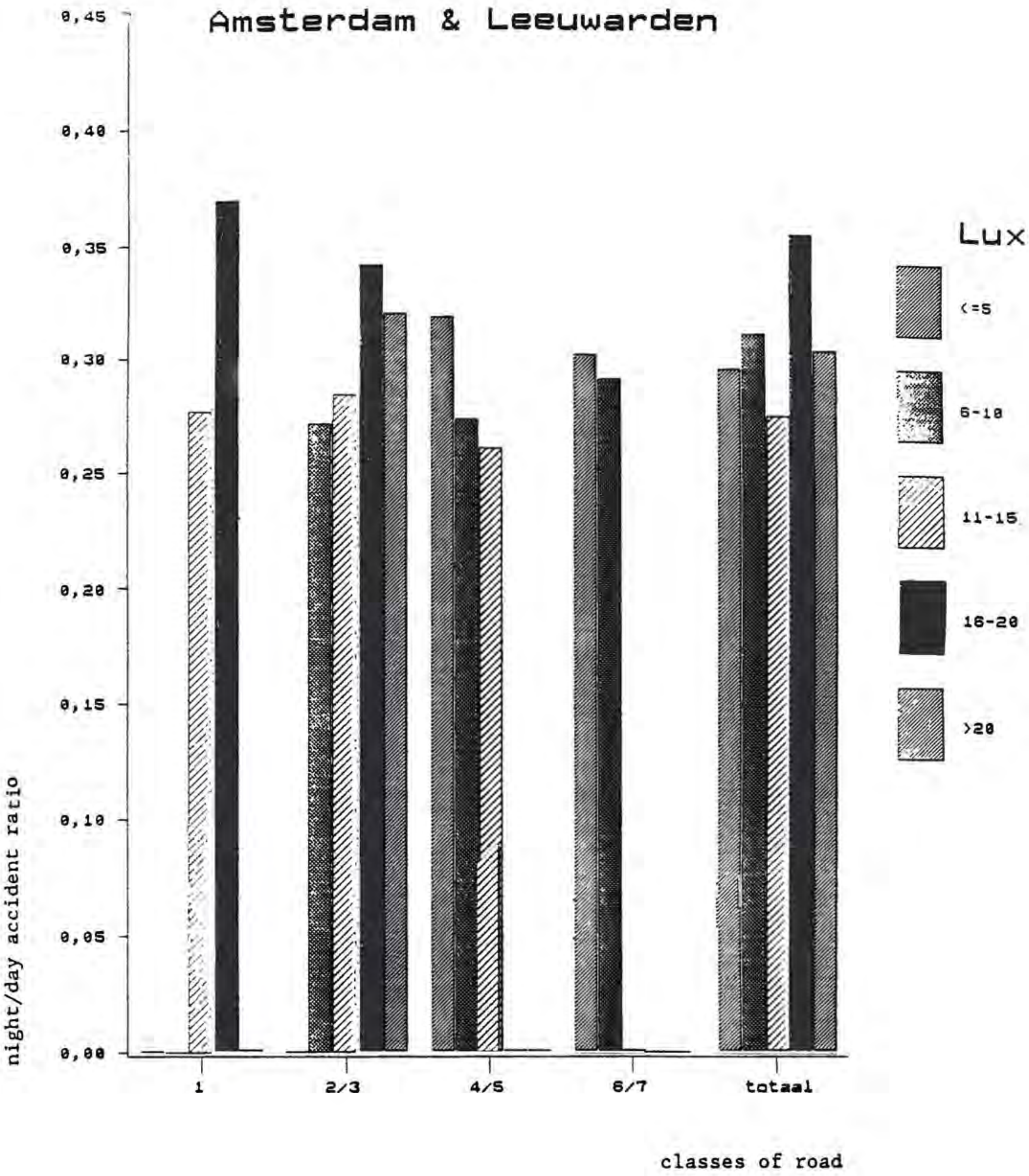


Figure 3. The night/day accident ratio for different classes of road and light levels (Amsterdam-West and Leeuwarden).

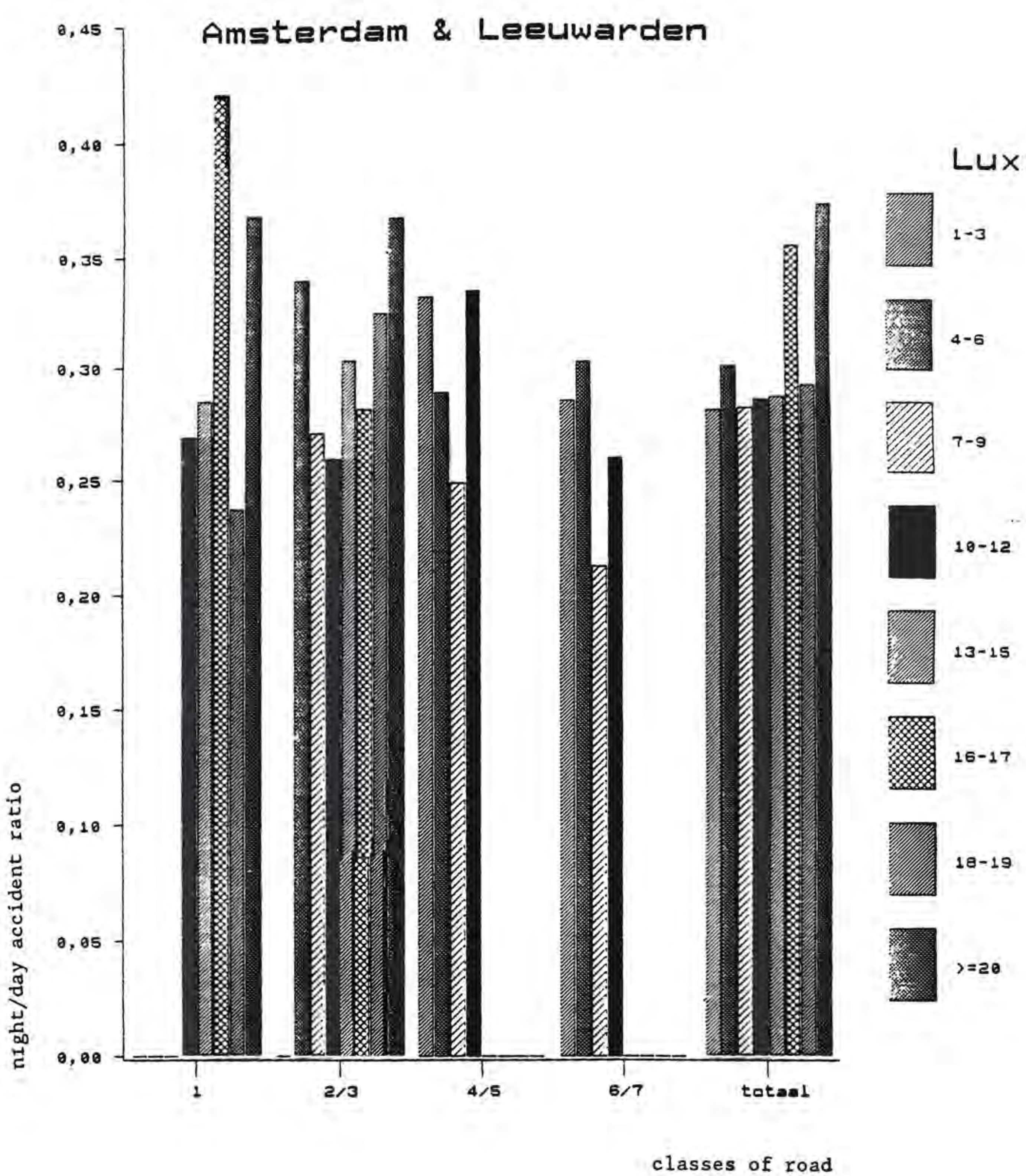


Figure 4. The night/day accident ratio for different classes of road and light levels (Amsterdam-West and Leeuwarden).

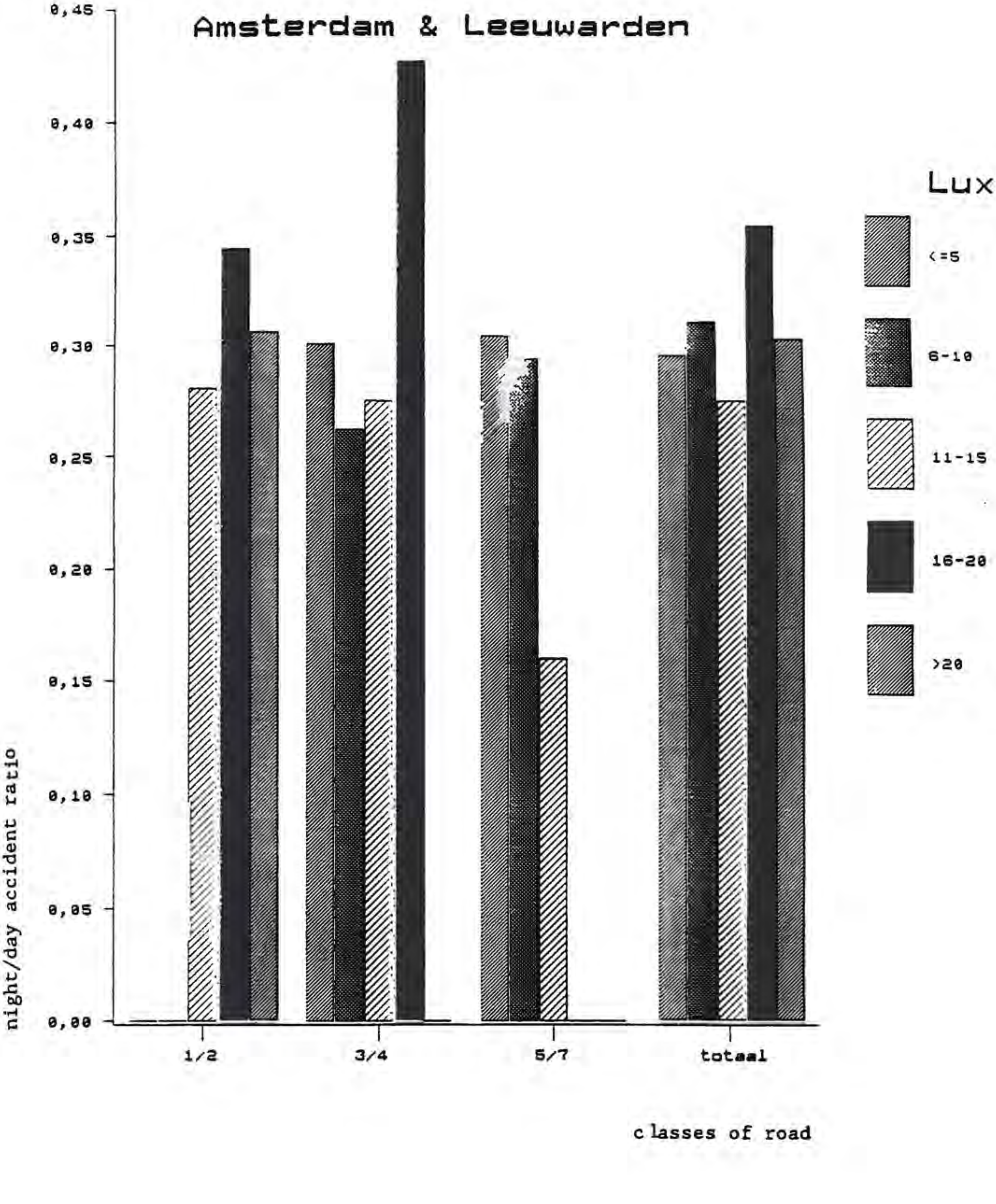


Figure 5. The night/day accident ratio for different classes of road and light levels (Amsterdam-West and Leeuwarden).

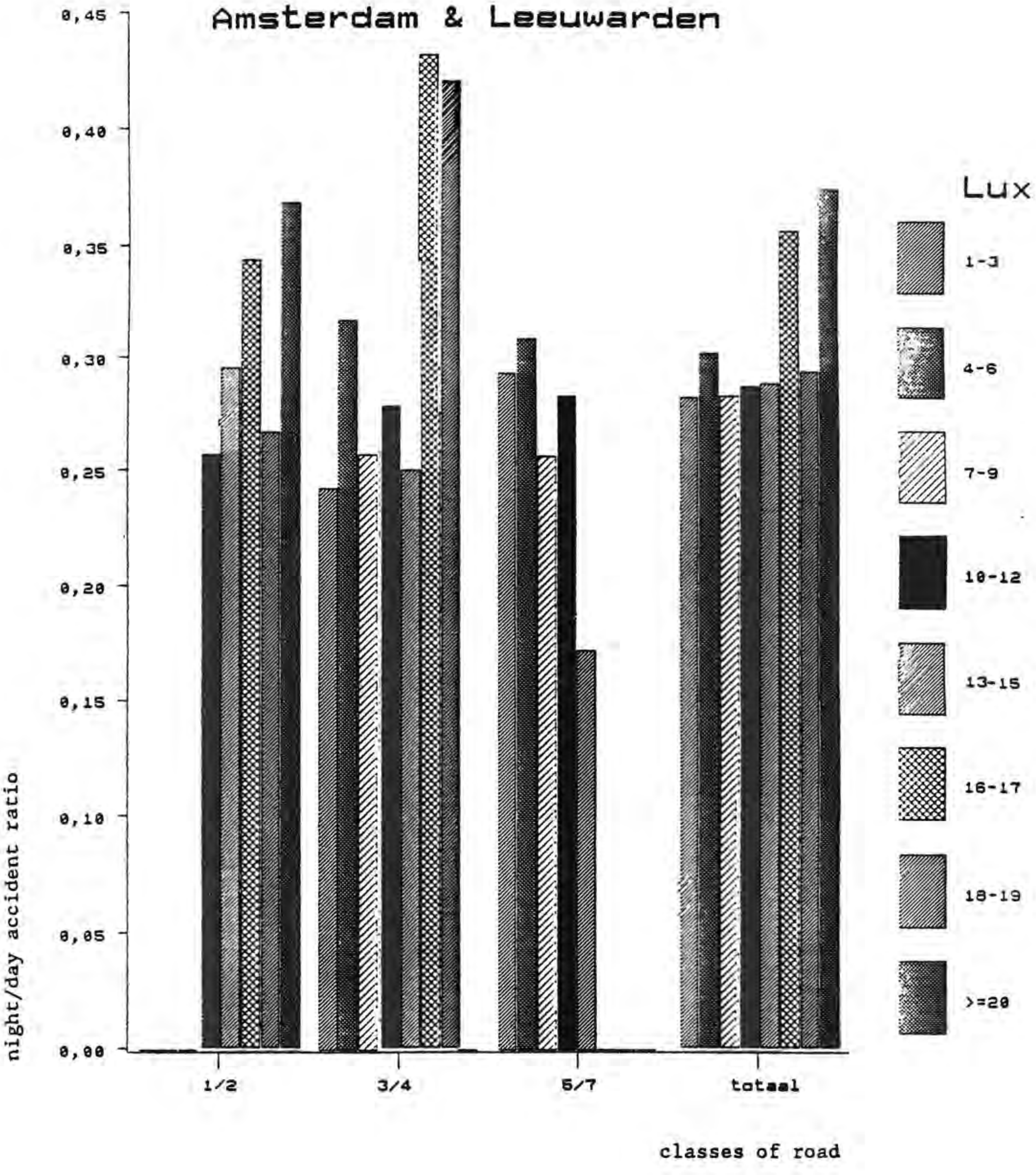


Figure 6. The night/day accident ratio for different classes of road and light levels (Amsterdam-West and Leeuwarden).

TABLES 1 - 8

Dual carriageway roads		class 1
Traffic routers (mixed traffic)		
Traffic intensity	high	class 2
	medium	class 3
	low	class 4
Residential streets		
Overall business	busy	class 5
	medium	class 6
	quiet	class 7
Shopping areas, parking lots, squares etc.		class 8

Table 1. Classification of roads.

Illumination (Lux)	Day	Night	Total	% Night	Ratio n/d
3	32	17	49	36,7	0,53
6	32	10	42	23,8	0,31
7	1	1	2	(50)	
8	3	1	4	(25)	
10	34	16	50	32	0,47
12	46	16	62	25,8	0,35
13	43	17	60	28,3	0,39
14	9	2	11	(18,2)	
15	21	18	39	46,2	0,86
20	3	1	4	(25)	
<5	32	17			0,53
6-10	70	28			0,40
11-15	119	53			0,45
>20	3	1			
1-3	32	17			0,53
4-6	32	10			0,31
7-9	4	2			
10-12	80	32			0,40
13-15	73	37			0,51
>20	3	1			

Table 2. Injury accidents Leeuwarden according to lighting (VOR-data 1986).

LEEUWARDEN

Lux	Dag								Nacht								Totaal		
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	dag	nacht	totaal
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	18	0	0	0	0	0	0	0	0	0	0	0	0	18	0	18
3	22	0	36	16	89	220	51	5	6	0	4	13	28	69	9	0	439	129	568
4	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	14	0	14
5	0	0	223	15	31	36	3	36	0	0	76	4	11	9	0	9	344	109	453
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	12	3	10	0	0	3	0	0	5	0	4	0	0	0	28	9	37
8	0	0	46	26	0	0	0	31	0	0	9	0	0	0	0	24	103	33	136
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	17	0	97	23	60	220	36	107	5	0	33	7	20	77	1	56	560	199	759
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	293	290	0	2	7	7	35	114	77	60	0	0	7	0	0	32	748	176	924
13	273	306	0	21	0	5	3	42	68	97	0	3	0	0	0	16	650	184	834
14	185	31	0	9	0	0	0	17	43	4	0	3	0	0	0	0	242	50	292
15	106	195	0	0	19	17	1	10	50	64	0	0	3	5	0	6	348	128	476
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	50	0	0	0	2	0	25	0	12	0	0	0	0	0	6	77	18	95
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Totaal	896	872	414	147	216	507	129	390	249	237	127	30	73	160	10	149	3571	1035	4606

Table 3. Daytime and nighttime accidents (Leeuwarden).

AMSTERDAM

Lux	Dag								Nacht								Totaal		
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	dag	nacht	totaal
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	1	0	0	1	64	518	1	0	0	0	0	2	18	180	0	585	200	785
5	0	0	0	0	1	164	5	34	0	0	0	0	1	33	1	1	204	36	240
6	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	2	2	4
7	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	1	2
8	0	0	208	31	66	54	2	16	0	0	58	12	18	10	1	2	377	101	478
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	3	0	72	4	0	0	0	39	2	0	13	0	0	0	0	10	118	25	143
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	84	47	0	11	0	0	8	0	32	15	0	2	0	0	3	150	52	202
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	23	0	0	0	0	0	0	0	8	0	0	0	0	0	23	8	31
15	2	141	7	0	0	7	0	7	0	39	1	0	0	0	0	0	164	41	205
16	269	151	73	1	0	0	1	0	113	31	32	0	0	0	0	0	495	176	671
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	135	119	41	0	0	0	0	0	32	30	18	1	0	0	0	0	295	81	376
19	0	28	21	0	7	0	0	0	0	13	7	0	2	0	0	0	56	22	78
20	84	413	0	0	3	0	0	1	35	163	0	0	8	0	0	2	501	208	709
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	41	103	0	1	0	0	0	0	11	33	0	0	0	0	0	0	145	44	189
Totaal	534	1040	492	37	89	289	526	109	193	341	152	13	33	183	20	20	3116	997	4113

Table 4. Daytime and nighttime accidents (Amsterdam).

AMSTERDAM EN LEEUWARDEN

Lux	Dag 1	2	3	4	5	6	7	8	Nacht 1	2	3	4	5	6	7	8	Totaal dag	nacht	totaal
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	18	0	0	0	0	0	0	0	0	0	0	0	0	18	0	18
3	22	0	36	16	89	220	51	5	6	0	4	13	28	69	9	0	439	129	568
4	0	1	0	14	1	64	518	1	0	0	0	0	2	18	180	0	599	200	799
5	0	0	223	15	32	200	8	70	0	0	76	4	12	42	1	10	548	145	693
6	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	2	2	4
7	0	0	12	3	10	0	0	4	0	0	5	0	4	0	1	0	29	10	39
8	0	0	254	57	66	54	2	47	0	0	67	12	18	10	1	26	480	134	614
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	20	0	169	27	60	220	36	146	7	0	46	7	20	77	1	66	678	224	902
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	93	374	47	2	18	7	35	122	77	92	15	0	9	0	0	35	898	228	1126
13	273	306	0	21	0	5	3	42	68	97	0	3	0	0	0	16	650	184	834
14	185	31	23	9	0	0	0	17	43	4	8	3	0	0	0	0	265	58	323
15	108	336	7	0	19	24	1	17	50	103	1	0	3	6	0	6	512	169	681
16	269	151	73	1	0	0	1	0	113	31	32	0	0	0	0	0	495	176	671
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	135	119	41	0	0	0	0	0	32	30	18	1	0	0	0	0	295	81	376
19	0	28	21	0	7	0	0	0	0	13	7	0	2	0	0	0	56	22	78
20	84	463	0	0	3	2	0	26	35	175	0	0	8	0	0	8	578	226	804
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	41	103	0	1	0	0	0	0	11	33	0	0	0	0	0	0	145	44	189
Totaal	1430	1912	906	184	305	796	655	499	442	578	279	43	106	222	193	169	6687	2032	8719

ca.1/3

ca.1/3

ca.1/3

Table 5. Daytime and nighttime accidents (Amsterdam and Leeuwarden).

Group	Class	Characteristic
a1	class 1 (dual carriageways)	high intensity
a2	class 2 + 3	high intensity
a3	class 4 + 5	average intensity
a4	class 6 + 7	low intensity
b1	class 1 + 2	traffic function
b2	class 3 + 4	distribution function (mixed function)
b3	class 5 + 6 + 7	destination function

Table 6. Clusters of classes of roads and of lighting.

Lux	1	2/3	4/5	6/7	Total
<=5			0,32	0,30	0,30
6-10		0,27	0,27	0,29	0,31
11-15	0,28	0,28	0,26		0,27
16-20	0,37	0,34			0,35
>20		0,32			0,30
Total	0,31	0,30	0,30	0,29	0,30

Lux	1	2/3	4/5	6/7	Total
1-3			0,33	0,29	0,28
4-6		0,34	0,29	0,31	0,30
7-9		0,27	0,25	0,21	0,28
10-12	0,27	0,26	0,34	0,26	0,29
13-15	0,28	0,30			0,29
16-17	0,42	0,28			0,36
18-19	0,24	0,33			0,29
>=20	0,37	0,37			0,37
Total	0,31	0,30	0,30	0,29	0,30

Table 7. Night/day accident ratio for different clusters of light level and of type of road.

Lux	1/2	3/4	5/7	Total
<=5		0,30	0,31	0,30
6-10		0,26	0,29	0,31
11-15	0,28	0,28	0,16	0,27
16-20	0,34	0,43		0,35
>20	0,31			0,30
Total	0,31	0,30	0,30	0,30

Lux	1/2	3/4	5/7	Total
1-3		0,24	0,29	0,28
4-6		0,32	0,31	0,30
7-9		0,26	0,26	0,28
10-12	0,26	0,28	0,28	0,29
13-15	0,29	0,25	0,17	0,29
16-17	0,34	0,43		0,36
18-19	0,27	0,42		0,29
>=20	0,37			0,37
Total	0,31	0,30	0,30	0,30

Table 8. Night/day accident ratio for different clusters of light level and of type of road.