DESIGN OF A STUDY INTO THE EFFECTS OF DRL ON ACCIDENT RATES

Methods of analysis and evaluation techniques

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FOREWORD

Since January 1990, the press and the media have been very critical about the set-up and execution of overseas studies investigating the use of day-time running lights (DRL), both nationally and internationally. There is also doubt about the status of vulnerable road users (pedestrians and bicyclists) following the introduction of DRL, and about possible negative influences on safety if DRL is not fully complied with.
This criticism has caused the Dutch Minister of Transport to postpone the introduction of DRL, pending a trial of the voluntary use of DRL in the northern provinces of the Netherlands. This would allow a number of uncertainties about the effectiveness of DRL to be studied, before deciding to introduce the measure on a nationwide basis.

If the trial goes ahead, it will be evaluated by the SWOV, at the request of the Transportation and Traffic Research Department (DVK) of the Department of Public Works. Part of the trial involves an accident analysis. This report offers an account of the manner in which the SWOV will assess the effectiveness of DRL and the doubts surrounding the measure.

The report is compiled by Mrs. J.E. Lindeijer. Mr. F.D. Bijleveld and Mr. S. Oppe contributed to the analytical and methodological aspects. Dr. P.H. Polak was primarily concerned with the statistical and physical problems. This has also led him to develop a formula for calculating the astronomical altitude of the sun.

INTRODUCTION

The analysis design is based on the political choice to stimulate DRL use within a test area in the Netherlands. In this way, the extent of its effect on road safety can be studied in the test area, provided that DRL use increases sufficiently in comparison with its use in the control area. It is expected that the DRL effect in the test area will result in a reduction in the (total) number of relevant accidents. It is also expected that this effect will not be as great for all types of traffic and under all circumstances and situations. Therefore, the analysis will consider the following: to what extent and for what groups are the effects expected to occur and to what extent do they differ from each other? The question concerning the reason for the difference can be answered if there is a theoretical explanation available about the question why DRL 'works'.

The general study questions include:

- Are there changes within and/or between the test area and the control area for each group and for various groups of road users?
- Can the differences be attributed to an increase in the use of DRL?
- In which situations/circumstances does the use of DRL contribute to road safety? To what extent and for whom?
- What effect does partial DRL use have on road safety?

1. STARTING-POINTS

1.1. Assumptions

The use of daytime running lights (DRL) is expected to affect accident rates. This effect is expected to vary for different categories of road users under different circumstances. For this reason, the following zero hypothesis will be tested for the evaluation of the effects in terms of accidents:

- No measurable changes occur in the groups distinguished in the test and control areas.
- There is no measurable difference between the test and control areas, either in the experimental or in the control groups.
- There is no measurable difference within the test and control areas between experimental and/or control groups.

The evaluation study is an empirical study intended, among other things, to test theoretical assumptions about positive and negative effects of DRL and to establish the seize of these effects. As such, the accident analysis provides an important aid in the search for a theoretical explanation for the effects of DRL. Conversely, the analysis itself will be improved if hypotheses derived from the theory can be used. At present, a theory on the effect of DRL is still under development.

It is generally assumed that DRL makes motor vehicles 'easier' to detect. Vehicles with DRL are seen 'earlier' or 'faster' (Hagenzieker, 1990). If one also assumes that vehicles are 'recognised' earlier and faster with DRL, and that recognition is necessary in evaluation and decision-making (as part of the driving process), the following line of reasoning can be used in formulating the hypotheses below:

- DRL increases the visibility (in terms of detection and recognition) of motor vehicles, which can consequently be observed earlier or faster.
- Earlier observation will lead drivers and other participants in traffic to respond earlier in emergencies.
- Responses may consist of swerving, braking etc.
- Such reactions will reduce the severity or incidence of accidents.

On the basis of this reasoning and the underlying assumptions, as well as the available literature, the following provisional hypotheses can be formulated:

- The effects of DRL (in terms of accident severity) on highspeed collisions on roads outside built-up areas will differ from those on roads within built-up areas. The average speed in built-up areas is lower than outside, which means that the severity of accidents is less in relative terms. However, the visibility distances (observation time) are in most cases shorter within built-up areas than outside.

- The effects of DRL will be greater in collisions between fast and slow-moving traffic than among fast traffic. One could deduce from this that the effects will be greatest in accidents involving fast-moving traffic and pedestrians, less for fast-moving traffic and cyclist and least for fast-moving traffic and moped-riders (Helmers, 1988). This hierarchy is based on the differences between the average speeds of road users involved in collisions: the lower the speed, the greater the chance that the slower-moving road user will be able to successfully perform an emergency manoeuvre.

- The effects of DRL in high-speed traffic will be greater for head-on and side collisions than for head-tail collisions (Helmers, 1988).

- There are indications in the literature that head-tail collisions would increase as a result of DRL. On this basis, the hypothesis predicts that the effect of DRL on head-tail collisions among fast traffic would be to increase the numbers of this kind of accident.

- On the basis of empirical data is to expect that the number of accidents caused by misjudged overtaking manoeuvres will decrease (KFV, 1989) and the number of head-tail collisions will increase (Stein, 1985).

- The effect of DRL will be greater in clear, dry weather than during rainy daytime weather. In rainy weather, large numbers of motor vehicles already drive with their lights on (Lindeijer & Bijleveld, 1990a).

- There will be no effects during rush hours in winter, but effects will be found in rush hours in other seasons. Light levels are very low during much of the winter rush hours and a very large proportion of motor vehicles (still) have their lights on (Lindeijer & Bijleveld, 1990a).

1.2. Analysis methods

The analysis methods used include: the 'intervention method' and the 'analysis method for specific effects'.

The intervention method establishes whether a change in the number of accidents occurs in connection with changes in DRL use in the after period with respect to the figure for the before period. Changes are measured between the test area and the control area and in relation to experimental and control groups in each of these areas (see before and after study, a.o.).
Example: Given a relative difference in multiple daytime accidents between the experimental group and the control group in the after period, DRL use in the after period will be considered for each of these groups; has DRL use in the control group remained relatively constant, while it has increased significantly in the experimental group?
The properties of this method are for instance that the number of accidents in a category easily satisfies the conditions necessary for performing statistical tests, so that even relatively small differences can be considered significant.
On the other hand the 'overall' effect between the categories is regarded. How this overall effect is composed remains unknown (e.g. from small to large effects under specific conditions and circumstances for specific groups of accidents). Working with unspecified conditions and circumstances increases the likelihood of alternative explanations for any effects found. This problem is reduced by also employing the analysis method for specific effects.

With the analysis for specific effects, groups of accidents are selected on the basis of DRL use.
Example: The categories of multiple daytime accidents (in the experimental and control group) are divided into sub-groups, based on the know-

ledge about differences in DRL use in the before period under specific circumstances. This analysis investigates how the effect of DRL carries over in the number of accidents. A small difference in accidents is expected if the percentage of DRL use was already reasonably high in the before period (e.g. accidents with motorcycles on motorways during clear, dry weather) while a great difference is expected if this percentage was quite low (e.g. accidents during clear, dry weather after 9 a.m. and before 7 p.m. in summer inside the built-up area).
The properties of this method are that effects in the categories thus defined can be measured more accurately and are more suitable for following trends over time than the intervention method would allow. In groups of accidents selected on the basis of DRL use, the DRL effect must be proven; in groups of accidents where a measured drop or rise is related to the
development in average DRL use (no regarding differences in DRL use) alternative explanations remain possible. The analysis for specific effects analysing the effect of DRL is unique; until now, no other study has tested for specific effects. In order to select accidents in this manner, reliable user data is required under different circumstances and for different situations in the before period; these are in fact available (see Chapters 5 and 8) and give the evaluation study an extra dimension.
On the other hand the number of accidents in the subgroups is often too small to permit statistical assessment. Even if a test could be carried out, relatively large differences are still harder to prove significant. However, if a measured effect confirms the expected effect the results for these subgroups will contribute to the judgement of the effectiveness of DRL.

In other words, a test for specific effects has less power than the intervention method (used in the Swedish analysis) to discriminate for significant effects; however, it does allow more reliable statements to be made about the extent to which DRL can make a specific contribution to road safety. The disadvantage is that these tests make generalised statements more difficult. By using both methods, it is expected that objections to the set-up and execution of the Swedish study (and other studies) can be overcome.

1.3. DRL use and accidents

Since November 1989, the use of DRL in the Netherlands is measured on a monthly basis. Apparently, there are differences in DRL use over time, according to vehicle category and according to circumstances and situations. The following variables are involved:

- the light level;
- the region;
- the location;
- the weather, time of day;
- working day/weekend day;
- type of road (motorway and other roads outside the built-up area; local and through roads inside the built-up area);
- inside versus outside the built-up area;
- type of vehicle;
- month; season.

To link DRL use to accidents, comparable variables from the accident records are needed. Variables that should be considered include:

- province
- inside or outside the built-up area
- month and day of the week
- hour of the day
- weather conditions
- type of traffic participation
- speed limit/traffic situation and/or type of accident

The use of DRL appears to be strongly related to the light level. The log-values of the measured light level (=loglux) explains over 41% of the variation in measured DRL use in its own right (Table 1) This variable is therefore considered as intermediary in estimating the probability, as a function of time, that DRL was used during an accident (see Chapter 2). Using the light level in the accident analysis creates a certain problem. The light level at the time of an accident can only be estimated on the basis of the accident data, because it is not recorded as such.
The most important predictors of light level that can be derived from the accident data include sun altitude (combination of time, geographic coordinates and day of the year) and weather. Information about the

weather is difficult to link to specific locations, even with access to meteorological data, due to the great local variations often found. This can probably be solved by attributing a mean value to the weather conditions reported on the accident form.
For the purposes of this study, a formula for the altitude of the sun has been developed. With this formula, the light level for each accident can be estimated (see Annex I). The question is: do explanations lose their power if the light level is calculated on the basis of this formula? This has been studied for a number of available user data. The results show that the theoretical light level, derived from the sun's altitude and weather conditions, regional effect, built-up or non built-up area, contribute to about 60% of the variation in use of DRL (see Table 1). This percentage is higher than the percentage level based on the measured light level (approx. 54%). This difference can be explained as follows: during the daytime, the light level varies markedly at five-minute intervals. During clear, lightly overcast conditions, the lux value varies from less than 30,000 lux to more than 100,000 lux. However, man is hardly perceptive of this changes (at this level of brightness). It may therefore be assumed that the wide distribution in light levels does not influence driver' lighting behaviour (switching lights on or off) under these conditions. In other words, use of the formula implies a loss of information (the short terms variation), although there is no reason to assume that this loss is essential for explaining lighting behaviour. It may therefore be said that the theoretical light level is an even better predictor than the measured light level.

To estimate the probability of DRL use in the event of an accident, two possibilities are now available: either to distinguish between experimental conditions (for each type of vehicle, single or multiple accident; inside or outside the built-up area; various types of conflict etc.) or to account for these experimental conditions. Accounting for different experimental conditions can only be done if there is a theory available that states a causal relationship between relevant circumstances, use of DRL and the generated effectiveness of DRL. Such a theory is still an infancy. The results of this evaluation study are to contribute to the development of this theory. Therefore, accounting for is not yet possible.

The following points are also important for the accident analysis:

- Below a particular light level (100 lux), virtually all cars and lorries or vans will use DRL. This is not the case with motorcycles. Although taken over the entire day, a far greater number of motorcyclists ride with their lights on (approx 76%), some motorcyclists already ride without light at approx. 30 lux (see Figures 2 to 5). A light level of 100 lux corresponds to the sun being approx. 3° below the horizon (see Figure 1);
- Above a particular light level (approx 20,000 lux), there is hardly question of a drop in DRL use any longer. The percentage of DRL measured under these light conditions is considered to be constant (C-value). This situation corresponds with an altitude of the sun at approx. 30° above the horizon (see Figure 1). Each vehicle category has its own C-value under specific conditions (e.g. dry weather, inside the built-up area, in the middle of the day, etc.; see Figures 6 to 9).

The limits of light level given here are based on results of an analysis over the first six months that use of DRL was measured in The Netherlands (November 1989 to April 1990). Other lux values might apply in the summer period, this can only be established if measurements are taken over an entire year.

In addition, from the user data it has been established that the function that states the relation between DRL use and light level expressed in the logarithm of the measured light level (=lux) can well be approximated by the cumulative Normal distribution. In this case the distribution runs from 100% to C% in stead of 100% to 0%. Consequently, use of DRL as a function of the light level can easily be specified using three parameters: the mean, variance and C-value (Lindeijer & Bijleveld, 1990a).

Based on the following criteria, the accidents in the before period are redefined as daytime, twilight and nighttime accidents:

- Accidents that occur during the period when the sun is still approx. 3° below the horizon (= light level of less than 100 lux), are defined as nighttime accidents. Nighttime accidents therefore include all accidents where it is assumed that virtually all motor vehicles are using DRL in the before and after period. This group therefore represents the accidents that are not influenced by the introduction of a DRL-regulation in the test and control area.

- Accidents that occur during the period when the sun is between 3° below the horizon and 30° above it (= light level between 100 lux and 20,000 lux) are defined as <u>twilight accidents</u>. In this category the use of DRL varies strongly, i.e between 100% and C%. Here the concept of 'twilight' is interpreted more broadly than usual; it covers a broader 'area' than is normally understood by the term.
- Accidents that occur when the sun is 30° or more above the horizon are defined as <u>daytime accidents</u>. With daytime accidents, DRL use is equal to its C-value.

Twilight and daytime accidents can now be devided in DRL-relevant and non-DRL-relevant accidents.
In this way, the categories of daytime, twilight and nighttime accidents are refined, thereby allowing greater accuracy with selection in the before period of accidents on the basis of use of DRL (see also Chapter 2).
With the aid of the means, variances and C-values, the expected developments of DRL use in the test area can be described and conditions drawn up for the selection of accident groups (Chapter 5).

In testing, a distinction is made for DRL-relevant accidents, where it is assumed an increase in the use of DRL will have an impact. Relevant accidents are therefore assumed to be multiple day and twilight accidents involving at least one motor vehicle. The non-DRL-relevant accidents represent the control groups.
Within the relevant and non-relevant accident categories, a distinction is made between:
- experimental and control groups;
- accidents between fast traffic and fast traffic versus slow traffic;
- side, frontal and head-tail collisions;
- pedestrians, cyclists and moped riders;
- a distinction will be made according to whether the accident occurred inside or outside the built-up area (per category or group).

The accident database used here consists of registered injury accidents and accidents with material damage only (MDO accidents). The registration level of injury accidents is more comprehensive than that for MDO accidents. In order to perform all planned analyses, sufficient accidents must be recorded. The use of data for injury accidents only would hamper the study comparing various relationships too much.

The results of the before measurements of DRL use show that DRL use differs per vehicle category. With dry clear weather in the daytime, the C-values for cars, (at a national level) measured in winter and spring, is approx. 6%; for motorcycles approx. 76% and for lorries or vans approx. 15% (Lindeijer & Bijleveld, 1990a).
Therefore the following types of accidents concerning fast traffic will be distinguished:
- cars versus slow traffic (type I);
- cars versus cars (type II);
- cars versus motorcycles (type III);
- cars versus lorries or vans (type IV);
- motorcycles versus slow traffic (type V);
- motorcycles versus lorries or vans (type VI);
- lorries or vans versus slow traffic (type VI).

From a statistical perspective, the first two conditions are particularly important for analysis, as these represent the largest groups in the accident database. The smallest groups are: lorries or vans among themselves, lorries or vans versus motorcycles and motorcycles among themselves. In addition, the difference in the number of accidents as a consequence of the anticipated effect will be greatest for types I and II, as it is anticipated that the measured difference between DRL use in the before and after period will be greatest for cars (see also Chapters 5 and 6).

1.4. DRL use and information

In the above, one of the aims for the measurement of DRL use has been described, i.e. for the purposes of the accident analysis. The measurement of DRL use is also intended to assist in advising information and stimulation campaigns and in evaluating these campaigns. Although superficially both aims seem to have little in common, it will be demonstrated that the description of conditions for the analysis of specific effects (Chapter 5) also offers enough interpretation possibilities to help establish the influence of campaigns on DRL use.

2. BASIC TESTING PRINCIPLE

The general idea: theoretically, the estimated effectiveness of DRL of 10% of the DRL-relevant accidents is based on an increase from 0% to 100% use of DRL. In practice, every measured effect of DRL will be one from more than 0% in the before period to less than 100% in the after period.

The ideal situation for evaluating the effect of DRL on the development of accidents would be if DRL use of motor vehicles involved in accidents were recorded. This is not the case, with the exception of some cities where the police do register this information (see Chapter 6 for further details). A good substitute would be if average DRL use in the direct vicinity of each accident were known; this is not available, either. However, the astronomical altitude of the sun (see Annex I) allows us to calculate the probable light level for the specific circumstances of each accident. Subsequently, given an encounter, both with or without DRL use, the probability can be estimated that either none, one or more vehicles involved used DRL. This can be done using the user data in the before period, taking into account certain conditions (e.g. rainy afternoon inside the built-up area).

The argumentation is as follows:

- There is a probability that <u>DRL is used with an encounter</u>, given a certain DRL level. This can be written as the probability that both, or one of the motor vehicles will use DRL. Expressed in a formula:

  P (DRL) = P (DRL for vehicle 1) * P(DRL for vehicle 2) +
  P (DRL for either of the two vehicles)

- The probability that <u>no DRL is used with an encounter</u>, given a certain DRL level, will then be : 1 - P (DRL).
- It is then assumed that the use of DRL will influence the probability of an accident. This influence (the effect) is expressed as: e (where e = 1 means that DRL use has no influence on the probability of an accident).
- The probability of an accident, given an encounter <u>without DRL</u> can be expressed as: <u>A</u>
- The probability of an accident given an encounter <u>with DRL</u>, will then be :

  A * e (where e does not equal 1)

- The total probability (all probabilities of a specific type of accident), given an encounter with or without DRL, can be expressed in a formula as follows:

$$A\ (tot) = P(DRL) * A * e + (1 - P(DRL)) * A$$

Test example: given condition I (cars versus cyclists, see para. 1.3), two hypotheses may be proposed:

- Hypothesis 1: if DRL use increases, the probability of an accident will be smaller, given an encounter with DRL use. Expressed in a formula:
  $A * e$, where $e < 1$
- Hypothesis 2: the more DRL is used, the greater the probability of an accident between cars and cyclists, given an encounter with DRL use. This means that the probability of an accident will be greater as a result of DRL use. Expressed in a formula:
  $A * e$, where $e > 1$

The following hypothesis will then be tested: there is no discernible difference between the before and the after period.
If this hypothesis is rejected the conclusion can be made that $e > 1$ or $e < 1$.

Tests are executed based on the ratio's of daylight, twilight and night accidents (para. 1.3) accounting for the above probabilities of DRL use. The DRL use for the twilight period will be its mean value; the DRL use for the daylight period will be the C-value.

Based on a calculation example, we can clarify what the influence on the expected number of accidents between cars in the after period will be, given DRL use in the before period.

- Suppose the effectiveness of DRL is 10% if the use of DRL increases from 0% to 100% (e = 0.90).
- Suppose that, if one of the cars were using DRL, the effect with the probability of an accident of this type would be half (5%) in comparison with the situation where both cars were using DRL (e = 0.95).
- Suppose that 10% of cars were already using DRL in the before period.
- Suppose that the DRL percentage increased from 10% through 50% to 80%.

Under such conditions, the probability of an accident, given an encounter between two cars - with or without DRL - can be described as follows:

Probability of DRL use	P (neither car DRL)	P (one car DRL)	P (both DRL)	P (total)
1% DRL	0.81	0.18	0.01	1.00
50% DRL	0.25	0.50	0.25	1.00
80% DRL	0.04	0.32	0.64	1.00

The total probability of accidents of this type (A(tot)), given an encounter with or without DRL can be calculated as follows:

Measured DRL use	No DRL	+	One car DRL	+	Both DRL	= K (tot)
10% DRL	0.81 * A	+	0.18 * 0.95 * A	+	0.01 * 0.90 x K	= 0.980 * K
50% DRL	0.25 * A	+	0.50 * 0.95 * A	+	0.25 * 0.90 x K	= 0.950 x K
80% DRL	0.04 * A	+	0.32 * 0.95 * A	+	0.64 * 0.90 * K	= 0.904 x K

As previously mentioned it is important that the analysis will primarily distinguish between groups of accidents with motorcars among themselves and motorcars against slow traffic. Furthermore corrections will be accounted for between distinguished conditions (e.g. built-up or non built-up areas, regions, weather circumstances).

3. BEFORE AND AFTER STUDY

3.1. General

Development in DRL use

The study concerns a before and after study with a test and control area. The accidents are divided into an experimental group (in the test area) and control groups (in the test and control areas). It is anticipated that DRL use will only increase in the test area and not, or hardly, in the control area. Based on this presupposition, it is assumed that the DRL effect will only be found in the test area (Lindeijer & Bijleveld, 1990b). Whether this assumption is realistic will be shown by the results measured. If it becomes apparent that DRL use in the control area has also increased but that the difference between the two areas still allows a comparative analysis, then this factor will be adjusted (see Chapter 2). Such a development does imply that the power of the tests is reduced. The comparison with independent control groups (night accidents) will always remain feasible if DRL use increases.
If the percentage for each group rises to about the same degree, the test must be considered a nationwide one. In that case, control areas abroad offer a possible alternative. The analysis problems related to an internationally comparable accident study will not receive further attention within the framework of this design.

An additional problem is the influence of stimulation campaigns and crossing traffic (traffic flow between the test and control area: Rest of the Netherlands). The provinces where this influence is expected to be least apparent include: Zeeland, North Brabant and Limburg. Therefore, the transitional areas must be subjected to more frequent measurements than has been the case till now, and at more locations. If necessary, the test area and the three southern provinces (= control area) will be analysed separately. This approach will be supplementary to the comparison with an adjusted 'overall' control area. The addition of this second analysis will enhance the reliability of the statements.

Other influences

Any other measures or influences on road safety, which generally do not correlate with anticipated DRL effects, are assumed to have a similar effect in both the test area and the control area. This will be controlled in the time series study by comparing the control groups in the test and control area with each other. Corrections can then be made on the basis of this trend analysis. Considering government plans to discourage use of the car, it is likely to suppose that this policy will have the most effect on traffic in the Western Region of the Netherlands (North and South Holland, Utrecht). If possible this can be adjusted by taking into account any changes in the exposure figures.

The before and after study looks at the following questions:
- Are there changes in the various groups within and/or between the test area and the control area?
- Does the measured effect relate to DRL use?

3.2. Categorising accidents

The accident database is subdivided into: 'test database' (accidents in the test area) and 'control database' (accidents in the control area). Per category, they are further subdivided into the number of accidents for daytime, twilight and nighttime situations respectively and according to the following categories:
- Multiple daytime and twilight accidents involving at least one motor vehicle. In the test area, this group represents the experimental group. Multiple daytime and twilight accidents are further distinguished into fast traffic and fast traffic versus slow traffic.
- Multiple nighttime accidents (categorised in the same manner as daytime accidents where possible).
- Single daytime and twilight accidents.
- Single nighttime accidents.

Subdivision of single accidents according to daytime, twilight and night-time is necessary to assess the influence of special police campaigns during the test period with regard to speed and drinking checks in the test and control areas that might influence only one of the sub-groups. Any further reference to daytime accidents is also understood to mean twilight accidents.

3.3. <u>Set-up and execution</u>

The intention is to maximize the power of the tests choosing to minimise the number of parameters for the estimation of the number of accidents in the after period. In the simplest model, the following parameters play a role:

- parameter A: time effect (before and after period);
- parameter B: relationship between test and control area;
- parameter C: relationship between DRL-relevant and non-DRL-relevant accidents.

The base table for the (log-linear) analysis to be performed uses the following variables:

- Year (e.g. 1988, 1989, 1990) * Area (control and test area) * Time of day (nighttime, twilight, daytime) * Time of the year * Spot (inside or outside the built-up area * Region * DRL relevance (multiple / single accidents) * Types of accidents (see para. 1.3) * Types of day (working- / weekend) * weather conditions (wet / dry).

This base table will be extended for specific conditions (e.g. rush-hour, season, type of road).

The effect of DRL can than be analysed using (third order) interaction between the A-, B- and C-parameters.

It will be clear that also other forms of interactions are investigated.

4. TIME SERIES ANALYSIS

4.1. General

An important piece of information about correction factors is derived from analyses of past accident data: the trend analysis, which will attempt to show the differences between the development of DRL-relevant accidents and non-DRL-relevant accidents. Time series analysis models used for this purpose can also include non-linear trends.
An example of such a model is the structural model of Harvey & Durbin (1986).

It must remembered that existing computer software will need to be adapted or supplementary programmes developed. As noted previously, an analysis of specific effects in relation to DRL is unique. For example, it concerns the analysis of ratios, rather than numbers (e.g. day-/nighttime accidents as a function of the C-values). Experience with these types of techniques has been limited until now, and extra effort is therefore required - not only to enable application of the selected analysis models - but also to extrapolate a specific pattern for the increase in DRL use, for example.

4.2. Set-up and execution

The analysis is directed at the following questions:
- How does the accident pattern for the various types of accidents and groups of road users develop within each separate study area and between the test and control areas?
- How does this development relate to the development in DRL use?

As noted previously, DRL use varies per vehicle category. This analysis distinguishes between vehicle categories. The time series analyses are conducted for the following:
- car passengers, categorised according to location (inside or outside the built-up area);
- motorcyclists;
- cyclists, moped riders and pedestrians, categorised according to location (inside or outside the built-up area);

and for these accident types:

- between fast traffic (see the conditions in para. 1.3);
- fast traffic versus slow traffic.

Only five years of MDO accident data is stored, therefore a time series analysis using injury accidents and MDO accidents can only go back five years from the date of commencement of the test.

The data on DRL use over the first six months gives reason to assume that DRL use also varies according to season and time of day (Lindeijer & Bijleveld, 1990a). That is why accident data is categorised according to time interval. The intervals are selected such that the differences in DRL use are maximised <u>between</u> intervals while differences in DRL use <u>within</u> the intervals are minimised. For example, during morning and evening peak times (before 9 a.m. and after 4 p.m.), use of DRL clearly differs from DRL use between 9 a.m. and 4 p.m.. The intervals that could therefore be selected for study might be morning and evening peak times, compared with the 'middle of the day'.

As was the case for the before and after study, the development of accidents over time during the after period is estimated on the assumption of constant policy, based on trend developments and/or available exposure data per category. If available, the exposure measure to be used might be a function of the transport performance, etc. per vehicle category.

This analysis will formulate additional hypotheses about the anticipated differences in the degree of effectiveness of DRL in relation to road user categories for the various types of accidents (see para. 1.1).

While measuring DRL use, a separate note is made of the number of cars driving with a broken lamp, in order to assess whether DRL use might create a new problem. If the number of people driving with a broken light were also to be measured at night, it would be possible to assess whether this factor affects the development of nighttime accidents. Although these measurements will not be carried out at night, attention will be paid to the likely influence of broken lamp(s) on the development of multiple nighttime accidents. It is assumed than if people drive with a broken lamp during the day, they will also do so at night.

5. ANALYSIS METHODS FOR SPECIFIC EFFECTS

5.1. General

One of the problems in demonstrating the effects of a measure is that in retrospect, alternative explanations can often be suggested for the effect ascribed. The more precisely the conditions under which the measure is considered to have an effect can be defined, the greater the change of proving the effect and the smaller the likelihood of an alternative explanation.

The problem is how to define the conditions in advance, and with what degree of accuracy, in order to come to a selection of accident groups in the before period (see Chapter 2).

5.2. Developments in DRL use

By stimulating DRL use (as is the intention for the test area), the use of DRL should increase to some extent. This rise can influence the anticipated distributions of DRL use in the after period in various ways. A number of possible circumstances are described below which, aside from no increase, could lead to various developments in the distributions of DRL use.

1. People will (continue to) use DRL at a higher light level. Therefore, the means for the cumulative DRL distributions as a function of light level will shift, although the standard deviations and C values will remain the same.
2. A greater percentage (C) of motor vehicles will have their lights on continuously. This means that the lowest percentage of DRL use measured in the daytime (C) will rise, although the mean and standard deviation will remain the same.
3. A combination of (1) and (2) occurs.
4. Information and/or stimulation can mean that motorists in (specific) situations and/or circumstances will more frequently use DRL simultaneously - the effect of being influenced by other road users. The average will either shift to a higher light level (1) or remain the same (2), but the standard deviation will be smaller; the S-curve of the distribution will be 'steeper'.

5. It is also possible than one group of motorists will not be affected by information campaigns etc. while another group will. As a consequence, DRL use in one group will not change in the after period, although it will in the other group. In this situation, the mean will not vary as much, but the standard deviation will be greater; the S-curve of the distribution becomes 'flatter', or more 'stretched out'.

This analysis will also be used to evaluate the effect of information campaigns and/or stimulation campaigns.

The before and after studies and time series analysis to be carried out have already been extensively described in Chapters 3 and 4.

6. STATIONARY ANALYSIS MODEL

6.1. General

In 1990, the municipality of Hoorn and four state police corps (since January), the municipalities of Arnhem and Sittard (since May) and Amsterdam (since June) commenced registration of vehicles involving in accidents using DRL or not. The police corps in the municipality of Dordrecht initially participated (since November 1989), but as their accident registration was computerised in 1990, the registration of DRL use could not continue.
Amsterdam, Arnhem and Sittard (in the control area) form part of a nation-wide measurement network; since November 1989, SWOV has been conducting monthly measurements of the use of DRL at these locations.
If one or several police corps in the test area would cooperate the analysis could also differentiate between the test area and the control area. If that is not possible, the analysis will only apply to the control area.

It could be that the registration of DRL use affects the registration behaviour of police. To study this factor, 'equivalent' municipalities (where DRL is not registered) are included as control group. Should this supposition prove to be true, this factor will be accounting for.

The study questions include:
- What is the probability of an accident, given an encounter with or without DRL, and
- Is the use of DRL by one of the collision partners (between fast moving traffic) just as effective as the use of DRL by both collision partners (see supposition with calculation example in Chapter 2)?

These questions can only be answered if it is known whether one or more of the vehicles involved was actually using DRL, and whether there remain sufficient non-DRL users. The latter is the case in this instance, provided there is no measured increase in DRL use in the control area (as anticipated).

The probability of an accident in an encounter with or without DRL is calculated on the basis of measured DRL use (see Chapter 2). It is then tested whether the registered accident statistics deviate from the calculated number of encounters.

6.2. Set-up and execution

In the stationary analysis model, there is question of a direct relationship between DRL use and accidents; there is no question of trend developments or influence due to changes in exposure data.

Example: Suppose a percentage of 10% DRL use is measured in Amsterdam. Based on this fact, the probability of an accident can be calculated when motor vehicles encounter each other at intersections with or without DRL:
- P(on/on) = (0.1 x 0.1) = 0.1
- P(on/off) = 2 x (0 .1 x 0.9) = 2 x 0.9 = 0.18
- P(off/off) = (0.9 x 0.9) = 0.81

The percentages based on the actual number of registered accidents are then entered in the table. Subsequently the hypothesis can be tested: there is no discernible difference between the calculated and the actual percentage distributions.
When completed, the base model looks as follows (per type of accident, see also Chapter 2):

	Calculated distribution	Actual distribution
P(DRL) on/on	0.01	0.005
P(DRL) on/off	0.18	0.10
P(DRL) off/off	0.81	0.895

If also police corps in the test area will cooperate a distinction can be made between cities in the test area and in the control area, in addition to the test described in the above.
Then, it may also be possible to calculate at what percentage DRL use will reach an optimal effect. This is important when determining whether to introduce the DRL-regulation on a national basis; this will determine the degree of effort required from police enforcement.

The analyses are conducted for the situation inside the built-up area and differentiated according to the conditions, between cars and between cars and pedestrians, cyclists and moped riders, provided sufficient accidents are available.

7. DEVELOPMENT OF THE RISK

'Risk' is understood to mean: the probability of an accident times the severity of the outcome (fatal, injured or MDO). This analysis will assess whether, under the influence of DRL, the risk will decline.

The argumentation followed is:
- by using DRL, motor vehicles can be 'better' or 'more quickly' observed (see para. 1.1);
- therefore they can respond more rapidly to an encounter;
- if an encounter still leads to an accident, the outcome of that accident will be less severe.

Based on this reasoning, it is expected that there will be a drop in fatal accidents. This type of accident will then be recorded under the category of injury accidents. There will also be a drop in the number of injury accidents. The proportion of fatal accidents that will shift to injury accidents will, seen absolutely, be smaller than the proportion of injury accidents that will shift to MDO accidents. Finally, the number of registered MDO accidents will also decline, as that share is again greater then the proportion of injury accidents.
In this way, it should be possible to calculate a risk measure.

8. RELIABILITY OF THE OBSERVATIONS

The value of the evaluation study will increase if - within the group of DRL-relevant accidents - those situations or circumstances where increase in DRL use is greatest can be defined; furthermore, if the experimental conditions can be differentiated according to DRL use. Therefore, the value of the study is largely dependent on the degree of reliability of DRL measurement.

To establish the reliability of the observations, it is necessary to demonstrate that:

- the observers are consistent in their measurement of DRL use;
- the measurements of light level are sufficiently consistent;
- the lux meters are calibrated.

The reliability of DRL use and the light level are determined on the basis of simultaneous measurements conducted for each observer, without his/her knowledge. The result of the simultaneous measurements and the 'normal' measurements are then compared. The degree of consistency determines the extent of reliability of the observations. The simultaneous measurements are performed with a test lux meter and by one and the same observer. Once a year, all lux meters are calibrated on the basis of the test meter.
The degree of consistency of the measurements and the light level is tested on a statistical basis.

8.1. Extending the measurement area

The test area will probably include three or four northern provinces. The Rest of the Netherlands will form the control area. It has already been noted that the greater the chance of working with clearly defined conditions on the basis of DRL use, the more accurately the expected effects can be measured and the trends over time can be followed. Particularly where it concerns a test area with a relatively small number of available accidents, it is important to track the development of DRL use with sufficient accuracy. At present, measurements are being taken at five locations spread over the test area (Region North: per road type inside or outside the built-up area and one location per degree of urbanisation). Additional locations are still needed, particularly for situations inside the built-up area (where the effect is expected to be greatest between slow traffic and fast traffic) and single lane roads outside the built-up area (see para. 1.1). Furthermore, extra locations will be selected for the 'transitional area' (between the test and the control area), in order to observe the influence of campaigns and/or crossing traffic on DRL use.

8.2. Control areas outside The Netherlands

With the introduction of a national DRL measure in The Netherlands, the use of control groups abroad should reinforce statements about the effect of the measure in the Netherlands. In the event the test area chosen is located within the Netherlands, the need for control areas abroad will be less.

Denmark will introduce the DRL measure on a nationwide basis in October 1990. This offers an opportunity to let the test area in the Netherlands 'join up with' Denmark, provided corrections can be made for differences between Denmark and the Netherlands in relation to exposure data, trend developments and types of accidents.

There are indications that Denmark conducted similar user measurements in the before period. If, based on these data:

- accidents can be selected on the use of DRL in the before period in Denmark, in a similar manner as has been described in this report;
- accurate conditions can be formulated in the same manner;
- the Danish data on DRL use are comparable to the data for the Netherlands;
- Denmark is able to categorise accidents in the same way as is described in the forgoing Chapters (see Chapters 2 to 7);

then identical accident analyses can be performed on an international scale.

The same reasoning can be followed to 'supplement' the control area in the Netherlands with control areas in for example, Nordrhein-Westfalen, the northern parts of France, Flanders and England, again provided that important differences between the countries can be adjusted.

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FIGURES 1- 9 AND TABLE

Figure 1. Percentages of passenger cars using DRL before (AM) and after (PM) the sun has risen to its maximum altitude as a function of the solar altitude, working days only.

Figure 2. Percentages of passenger cars using DRL (Nov. 1989 through June 1990) summed over classes of log(lux) (one unit log(lux) is five classes) as a function of the lux value.

Figure 3. Percentages of vans or lorries using DRL (Nov. 1989 through June 1990) summed over classes of log(lux) (one unit log(lux) is five classes) as a function of the lux value.

Figure 4. Percentages of motorcycles using DRL (Nov. 1989 through June 1990) summed over classes of log(lux) (one unit log(lux) is five classes) as a function of the lux value.

Figure 5. Percentages of mopeds using DRL (Nov. 1989 through June 1990) summed over classes of log(lux) (one unit log(lux) is five classes) as a function of the lux value.

Figure 6. Percentages of cars using DRL (Nov. 1989 through June 1990) summed over classes of log(lux) (one unit log(lux) is five classes) as function of the lux value, for dry and wet weather.

Figure 7. Percentages of vans and lorries using DRL (Nov. 1989 through June 1990) summed over classes of log(lux) (one unit log(lux) is five classes) as a function of the lux value, for dry and wet weather.

Figure 8. Percentages of motorcycles using DRL (Nov. 1989 through June 1990) summed over classes of log(lux) (one unit log(lux) is five classes) as a function of the lux value, for dry and wet weather.

Figure 9. Percentages of mopeds using DRL (Nov. 1989 through June 1990) summed over classes of log(lux) (one unit log(lux) is five classes) as a function of the lux value, for dry and wet weather.

Table 1. Percentages explained variation of variable logit = % DRL on / % DRL off, using the logarithm of lux value and the monotone transformation of the solar altitude, classified in classes of five degrees.

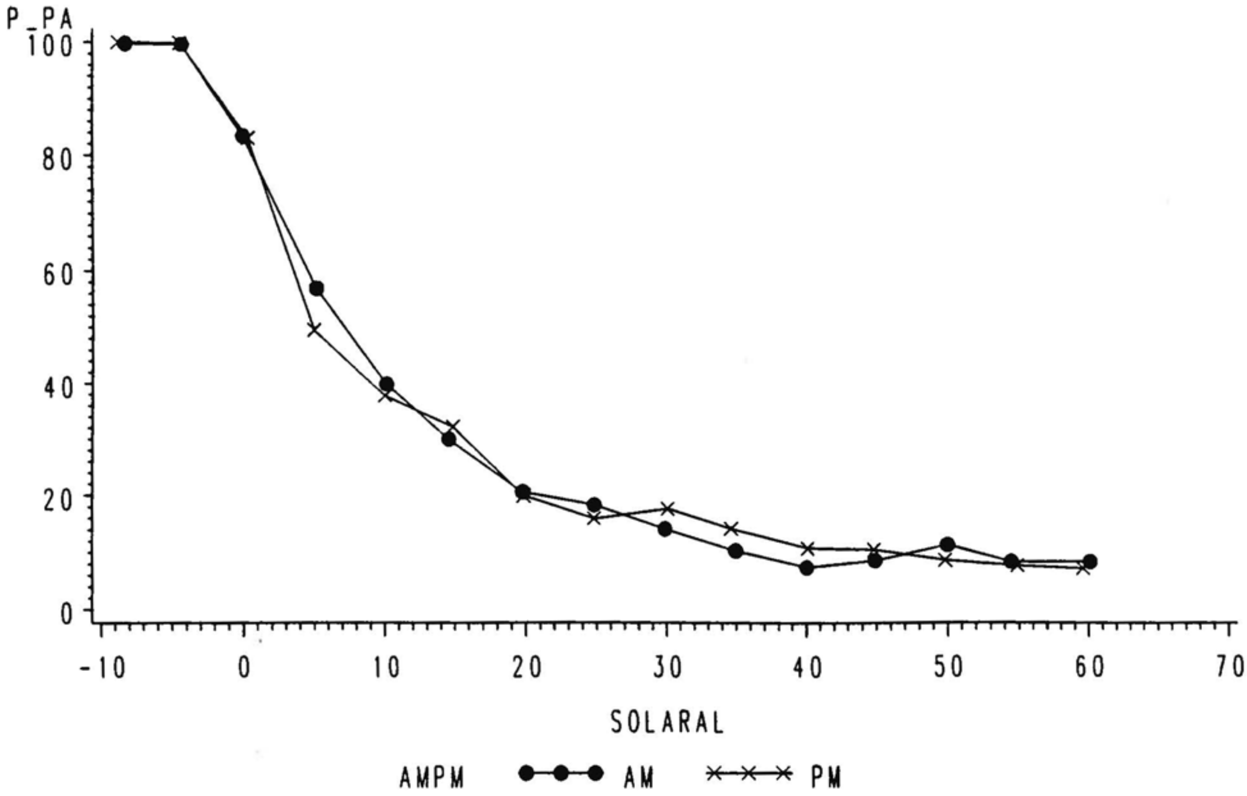
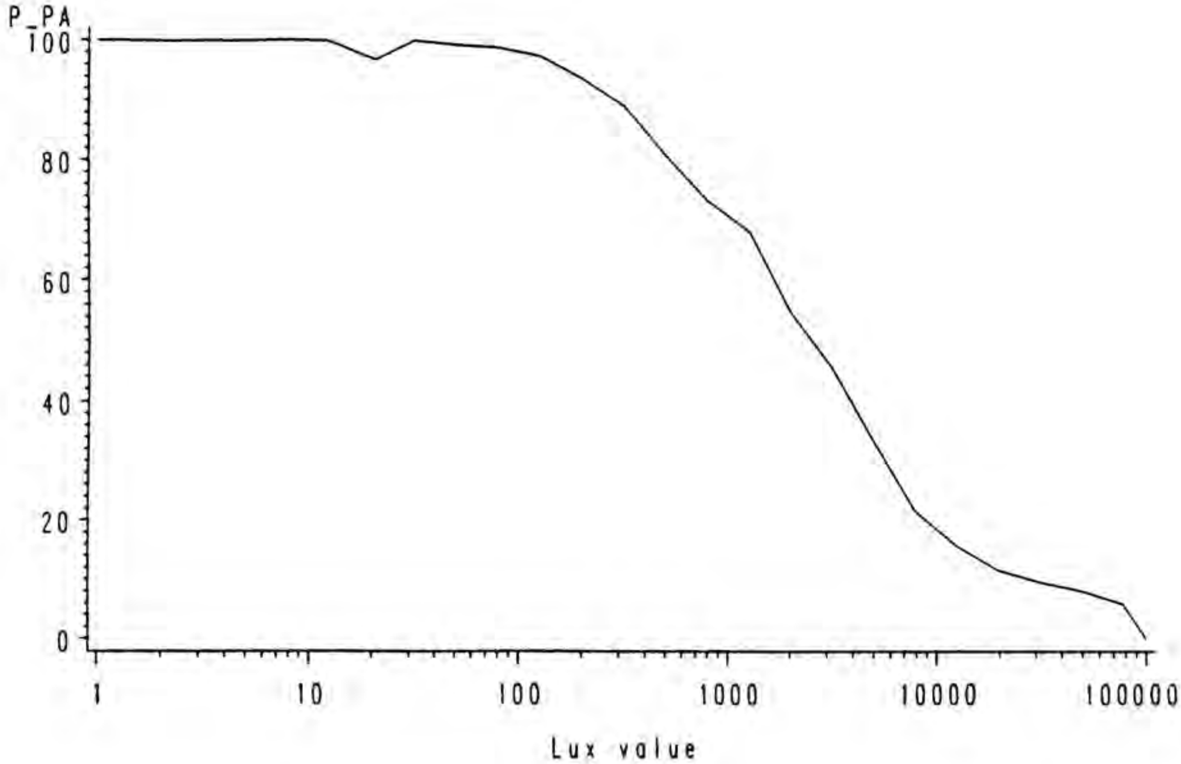
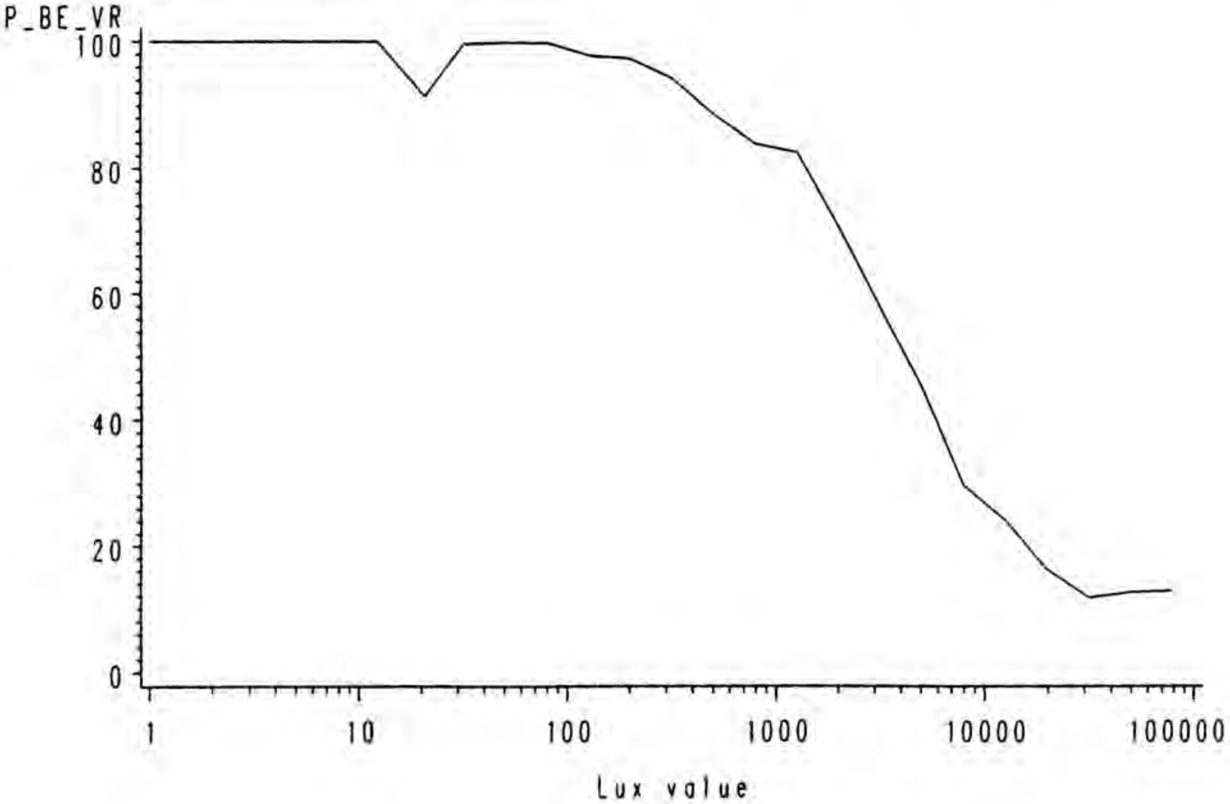


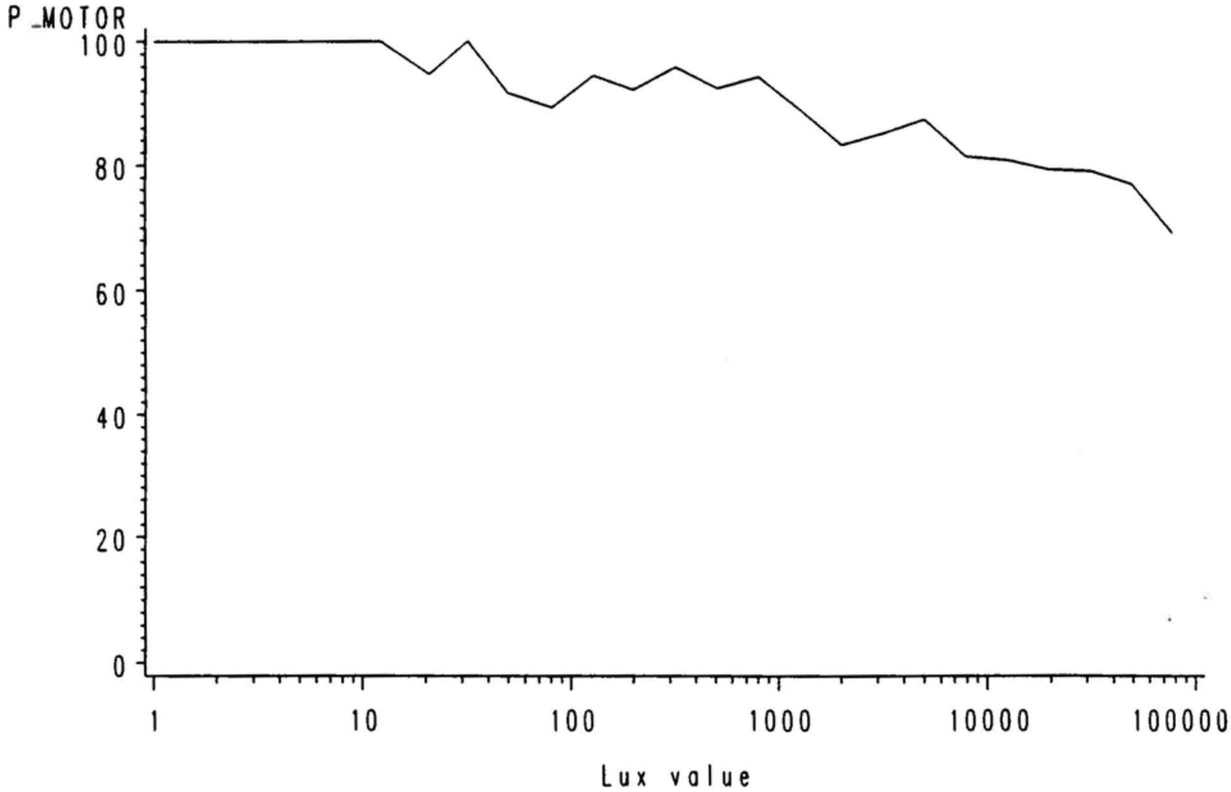
Figure 1. Percentages of passenger cars using DRL before (AM) and after (PM) the sun has risen to its maximum altitude as a function of the solar altitude, working days only.



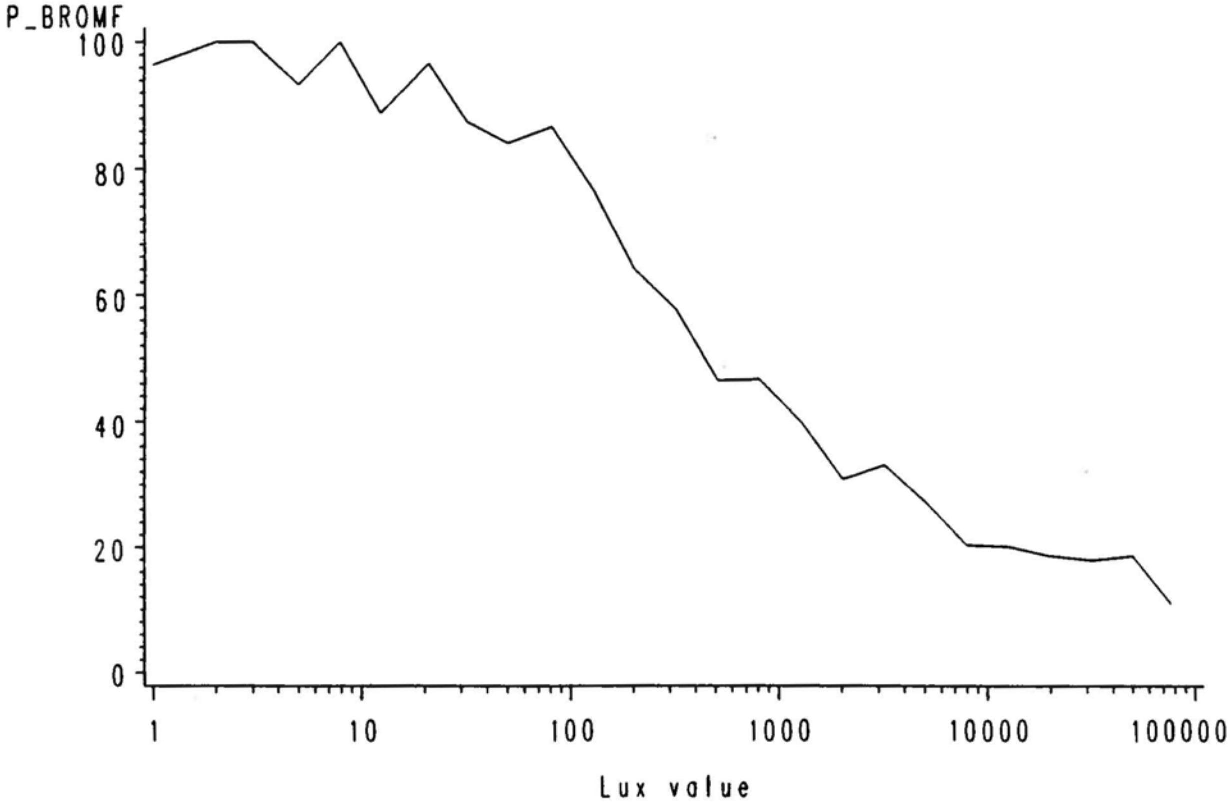
<u>Figure 2.</u> Percentages of passenger cars using DRL (Nov. 1989 through June 1990) summed over classes of log(lux) (one unit log(lux) is five classes) as a function of the lux value.



<u>Figure 3.</u> Percentages of vans or lorries using DRL (Nov. 1989 through June 1990) summed over classes of log(lux) (one unit log(lux) is five classes) as a function of the lux value.



<u>Figure 4.</u> Percentages of motorcycles using DRL (Nov. 1989 through June 1990) summed over classes of log(lux) (one unit log(lux) is five classes) as a function of the lux value.



<u>Figure 5.</u> Percentages of mopeds using DRL (Nov. 1989 through June 1990) summed over classes of log(lux) (one unit log(lux) is five classes) as a function of the lux value.

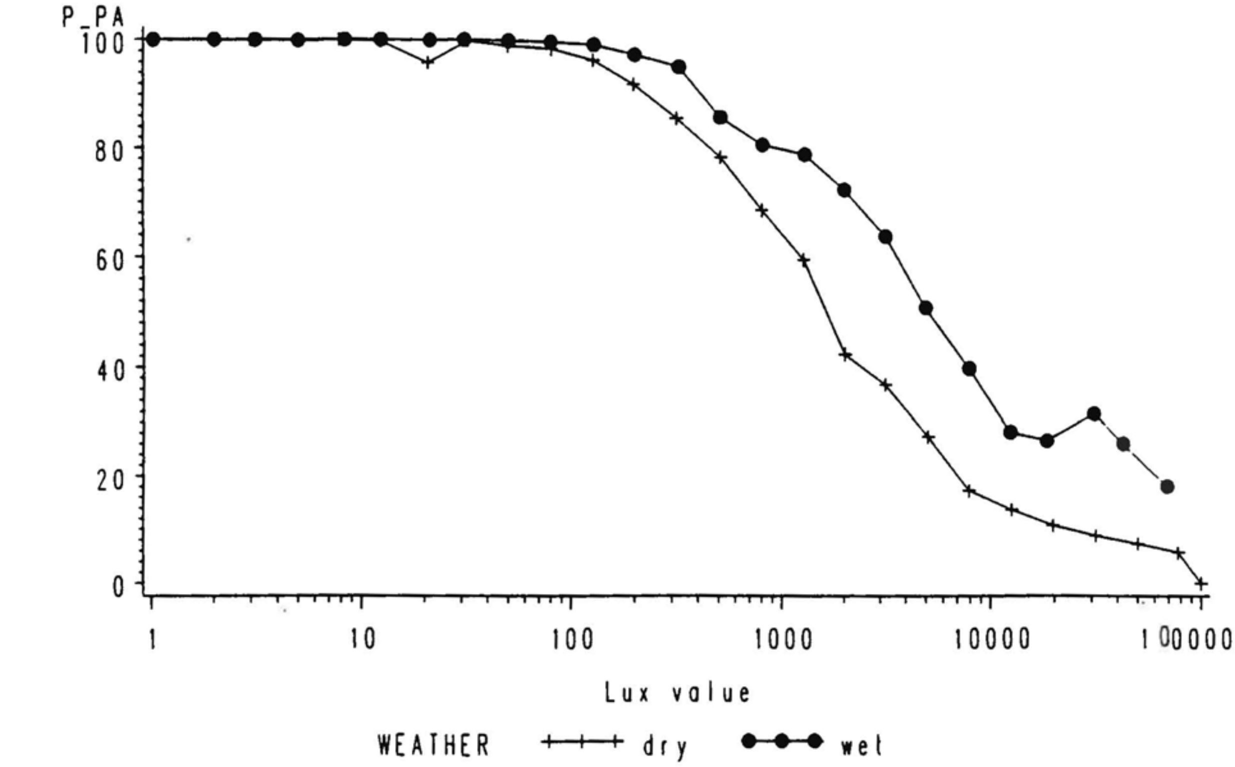


Figure 6. Percentages of cars using DRL (Nov. 1989 through June 1990) summed over classes of log(lux) (one unit log(lux) is five classes) as function of the lux value, for dry and wet weather.

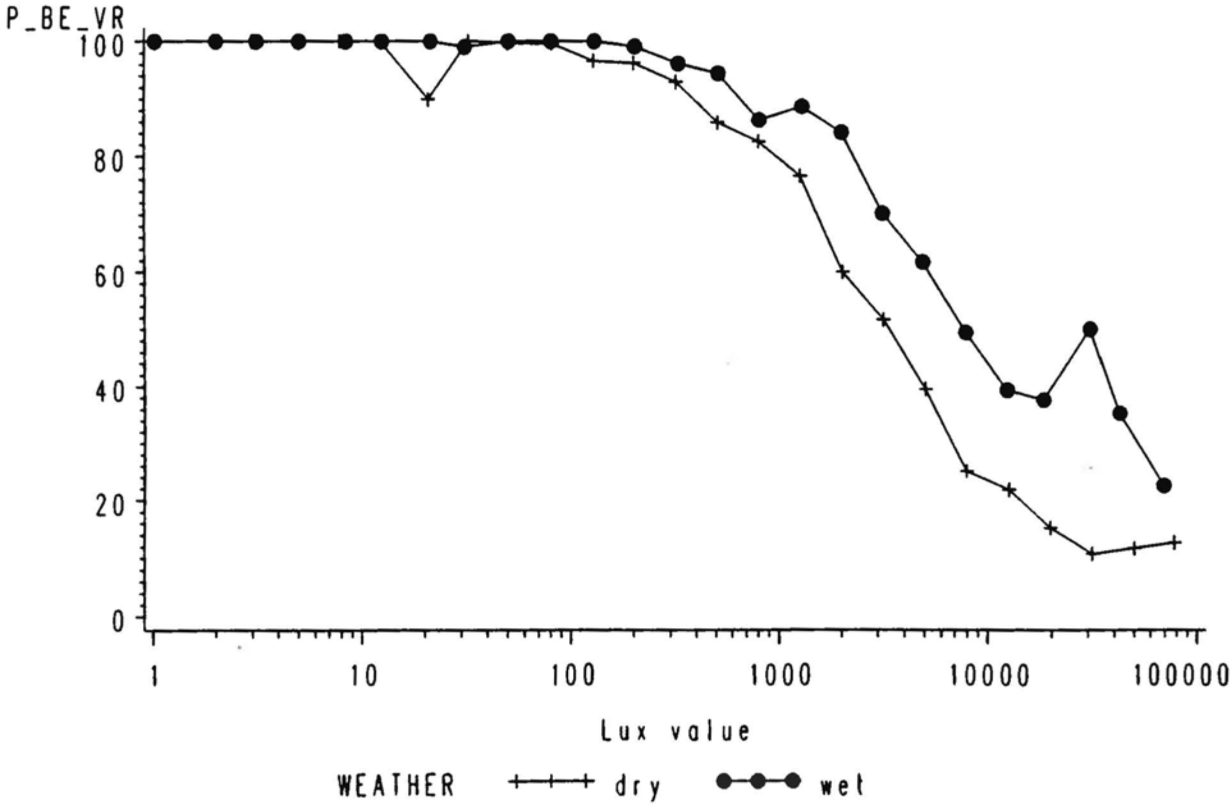
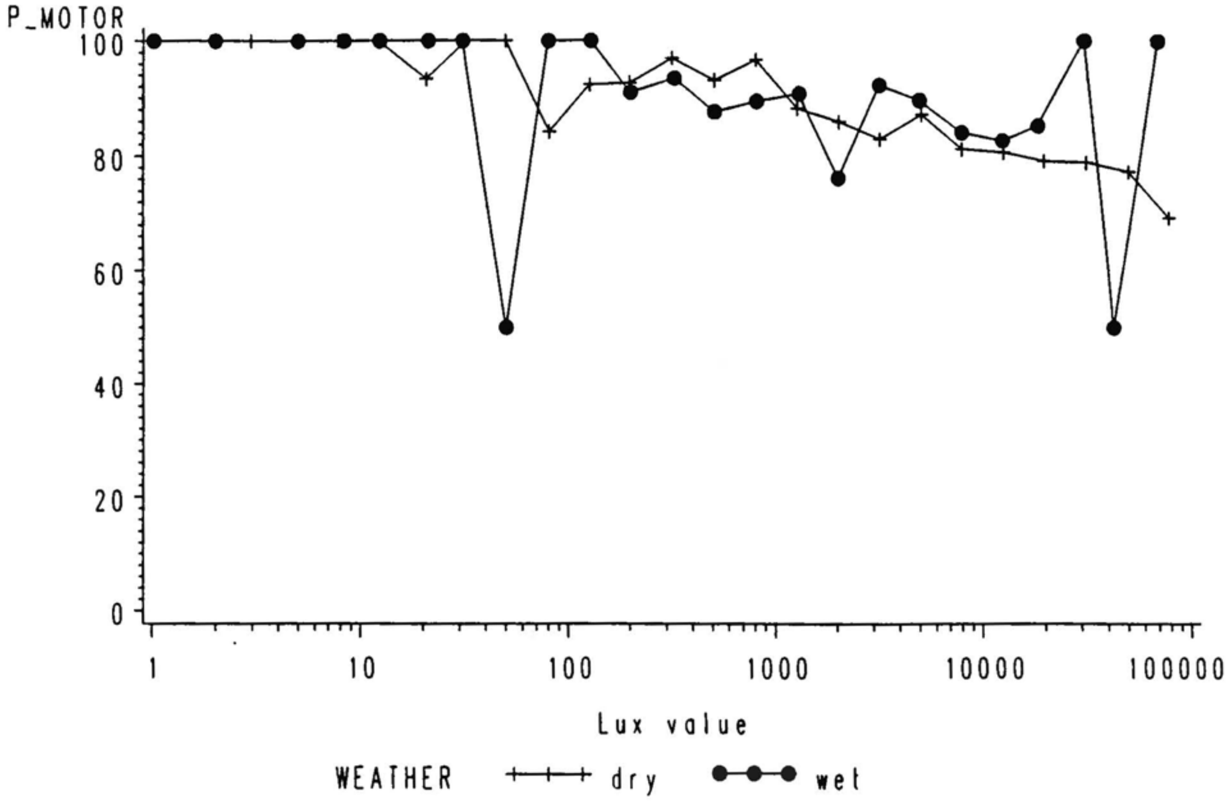
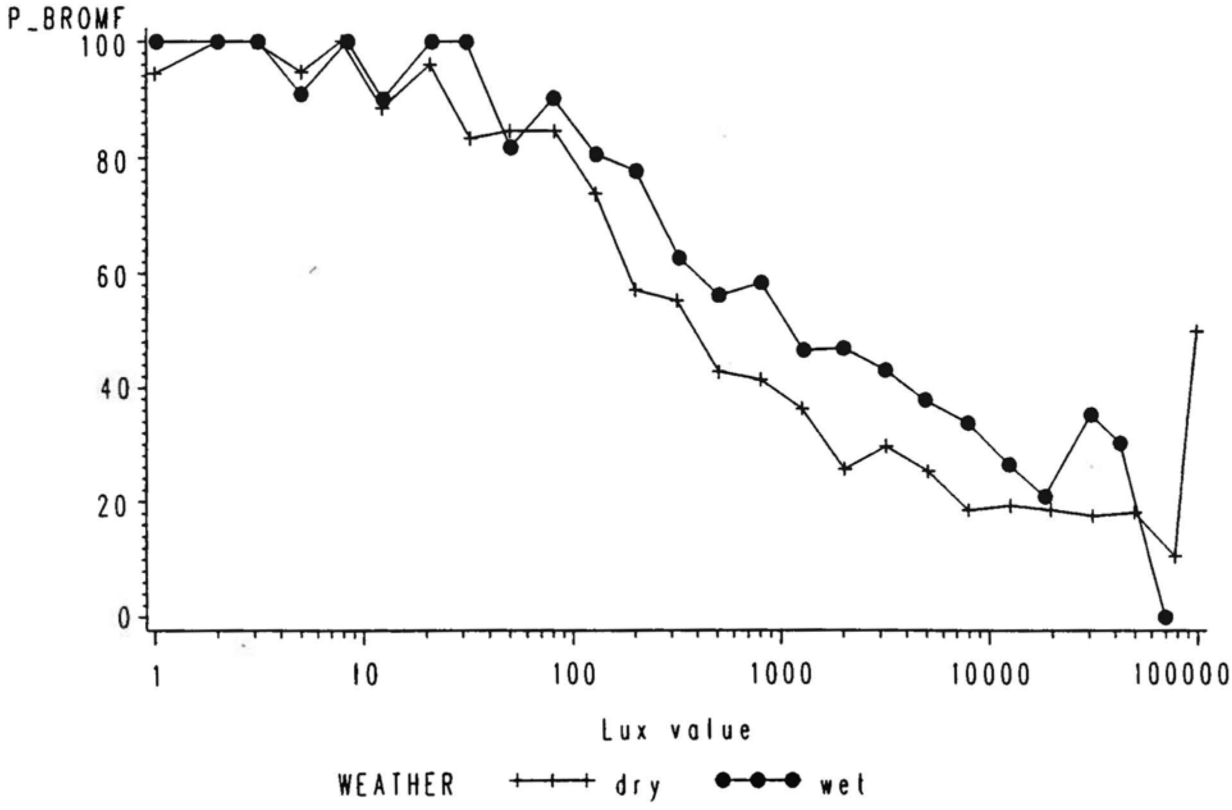


Figure 7. Percentages of vans and lorries using DRL (Nov. 1989 through June 1990) summed over classes of log(lux) (one unit log(lux) is five classes) as a function of the lux value, for dry and wet weather.



<u>Figure 8.</u> Percentages of motorcycles using DRL (Nov. 1989 through June 1990) summed over classes of log(lux) (one unit log(lux) is five classes) as a function of the lux value, for dry and wet weather.



<u>Figure 9.</u> Percentages of mopeds using DRL (Nov. 1989 through June 1990) summed over classes of log(lux) (one unit log(lux) is five classes) as a function of the lux value, for dry and wet weather.

	Log(lux)	Solar-altitude
Without any connection	0.414440	0.44615
Weather/road- condition*	0.460071	0.50750
Visibility	0.490573	0.52120
Weather	0.469763	0.54089
Road-condition	0.458563	0.50241
Weather road-condition	0.485385	0.55661
Weather location	0.574514	0.65192
Weather non-/built-up region	0.540314	0.61076
Weather non-/built-up region month	0.565189	0.63208
Month weather location	0.600643	0.67337

Data November 1989 through April 1990.

* Combinated variable. One category is dry weather conditions and dry pavement. Otherwise is the second category.

Table 1. Percentages explained variation of variable logit = % DRL on / % DRL off using the logarithm of the lux value and the monotone transformation on the solar altitude, classified in classes of five degrees.

ANNEX I

THE FORMULA USED TO CALCULATE THE ALTITUDE OF THE SUN

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1. Introduction

An important factor in describing the DRL behaviour of road users is the light level at that time, which is strongly correlated to the sun's position. There was therefore need for an algorithm which could calculate the sun's altitude in degrees above or below the horizon on the basis of the day and time (EPOCH) and geographical location. In practice, this value is often calculated with the aid of tables and additional formulas, but this did not suit our purpose.
The principle is based on two tables from the Sterrengids 1990 (Astronomical Guide), published by 'de Koepel' Foundation.

2. The altitude of the sun

The altitude of the sun (A) varies at every location on earth, being a combination of a daily and an annual cycle. The annual cycle is expressed by the declination (D) and varies between +23°26' (June 21) and -23°26' (December 22). The daily cycle is linked to the time of day. For a particular location on earth, defined by its geographical latitude (La) and longitude (Lo) and by the true solar time (ST) and declination (D) at a particular EPOCH, the sun's altitude is calculated on the basis of the following spherical trigonometry formula:

$$\sin(A) = \sin(La)\,\sin(D) - \cos(La)\,\cos(D)\,\cos(ST*\pi/12) \qquad (1)$$

In order to apply this formula, one also needs the formula for the declination as a function of the EPOCH and the formula for the true solar time as a function of the EPOCH and the geographical longitude. With all these formulas, the angles must be expressed as radians, which is why the factor $\pi/12$ is used (so that ST may be converted from hours to radians).

3. The declination

The Astronomical Guide includes a table headed 'The Sun in 1990'; this lists the declination of the sun for every fifth day after January 1 1990 on the basis of 0^h Universal Time (UT), also known as Greenwich Mean Time. In order to interpolate between these values, a function is fitted to provide values with the same degree of accuracy as the table:

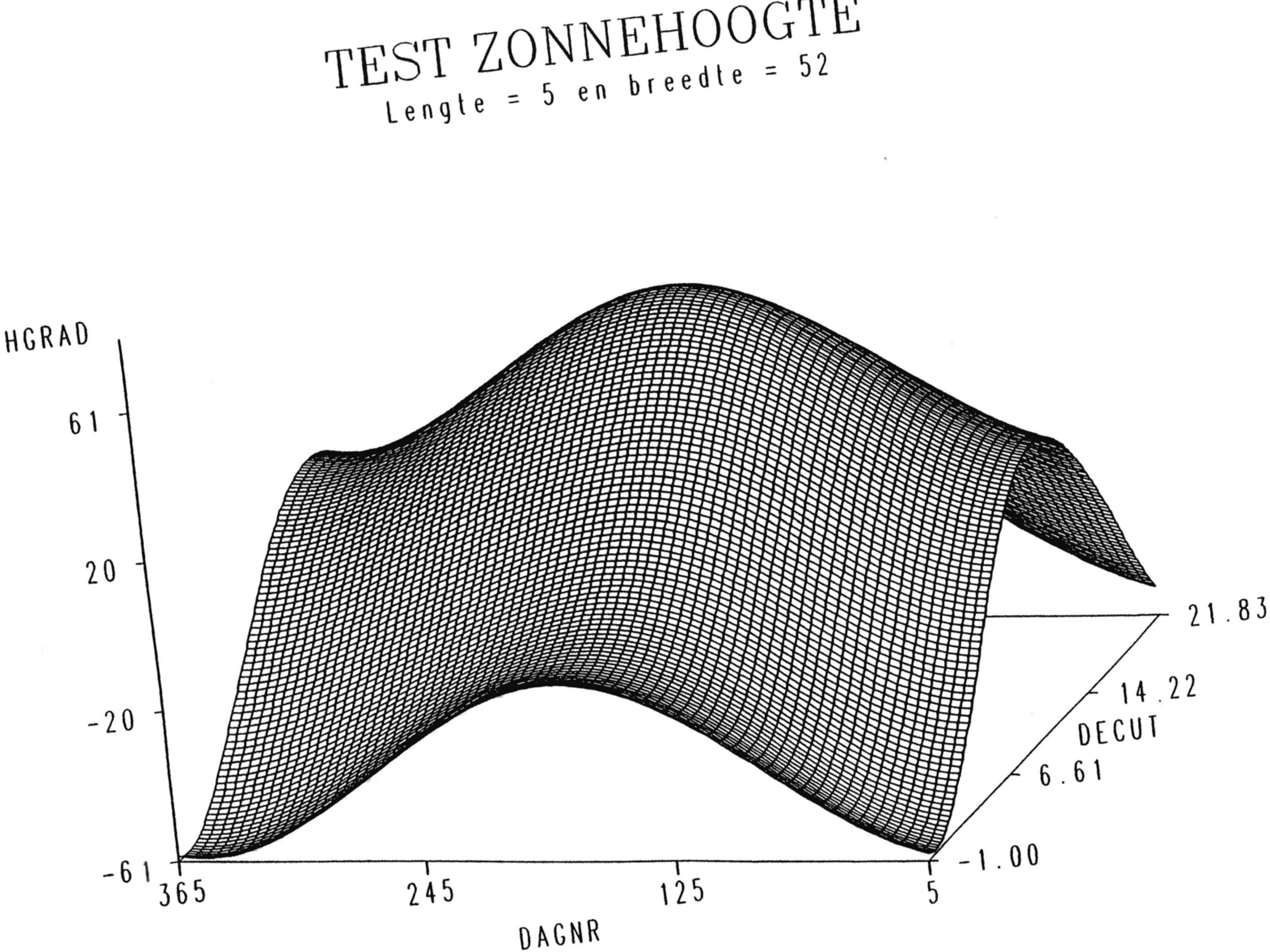
$$D = 0.40605 * \sin (0.0172028 * (EPOCH - 80.624) + 0.033 * \sin (0.0172028 * (EPOCH - 2.714))) - 0.00298 * \sin (0.0516084 * (EPOCH - 80.9)) \quad (2)$$

The first line represents the principal part, consisting of a sine with a period of one year ($0.0172028 = 2\pi/365.242$, with 365.242 being the length of the tropical year in days), the second line represents a small asymmetry in the annual movement of the sun, caused by the elliptical orbit of the earth around the sun and the third line represents an even smaller correction whose frequency is three times that of the principal movement. The EPOCH variable is the time of sun observation, expressed in decimal days that have passed since January 1 1990, 00:00:00 hrs UT; it is calculated on the basis of the date and local time, by correcting for the time difference with UT in the Netherlands: less 1 hour during wintertime and less 2 hours during summertime. For example, 13.00 hours at 1-1-1990 is equivalent to EPOCH = 0.5000, while 19.00 hours at 31-12-1990 is equivalent to EPOCH = 364.75.

4. The true solar time

The daily movement of the sun for a particular location on earth is mainly dependent on the local time (LT). However, it must be remembered that in the Netherlands the same legal time is in force at any given location, i.e. the Middle European Time (the local time at a meridian of 15° eastern longitude), which is one hour later than UT (with a two-hour difference in the summertime). In order to convert to the local time of a given location, it is necessary to calculate back to UT and then calculate the time difference with UT from the eastern longitude:

$$LT = \text{legal time} - 1 + \text{eastern longitude}°/15° \quad (3)$$



TEST ZONNEHOOGTE
Lengte = 5 en breedte = 52
HGRAD
61
20
-20
-61
365
245
125
5
DAGNR
21.83
14.22
DECUT
6.61
-1.00

For summertime calculations, the 1 is substituted by 2. The formula provides the local (average solar) time in hours.
A second correction must be carried out for this local time, i.e. a time adjustment (Ad), which is also made necessary by the elliptical orbit of the earth around the sun. Therefore, the true sun will be ahead of, or behind, local time (up to approx. 15 minutes). This correction for time is also listed in the tables of the 1990 Astronomical Guide, and again an adjustment function has been fitted:

$$Ad = 0.1225 * \sin(0.0172028 * (EPOCH - 186)) + 0.165 * \sin(0.0344056 * (EPOCH - 80.8)) \quad (4)$$

The two terms are a sine with a period of one year and one with a double frequency. This gives us the true solar time, in hours:

$$ST = LT + Ad \quad (5)$$

After entering formulas 3 and 4 in 5, and 2 and 5 in 1, we obtain the sine of the sun's altitude, from which A can be derived. The sun altitudes calculated with the aid of this algorithm are compared with the table, the greatest deviations being approx. 0.1°.