Ministerie van Verkeer en Waterstaat

Directoraat-Generaal Rijkswaterstaat

Adviesdienst Verkeer en Vervoer

Dynamic public lighting

Cover report

March 1999

Dynamic public lighting

Cover report

March 1999

Colophon

Published by:
Ministry of Transport, Public Works and Water Management
Directorate-General of Public Works and Water Management
Transport Research Centre (AVV)
P.O. Box 1031
3000 BA Rotterdam
The Netherlands

Final version, dated 21-12-1998

Editors:
E. Folles Transport Research Centre (RWS)
J. IJsselstijn Transport Research Centre(RWS)
J.H. Hogema TNO Human Factors Research Institute
A.R.A. van der Horst TNO Human Factors Research Institute

Lay out :
Ruud Overweg (AVV)

Table of contents

Management abstract

The Ministry of Transport, Public Works and Water Management is considering the feasibility of dynamically switching the lighting on motorways. This would provide under all traffic and weather conditions adequate illumination levels without illuminating the road unnecessarily brightly. This has been put into practice in a test conducted under contract of the Ministry of Transport, Public Works and Water Management, Transport Research Centre into the effect of dynamic illumination of motorways on driving behaviour and traffic safety.

The first step was to establish on the basis of a scene analysis a preliminary switching schedule. Besides the *normal* level of illumination (100%) a *reduced* (20%) and an *increased* level (200%) was employed. When it becomes dark, at least the reduced level is switched on. For normal to high traffic volumes the normal level is switched on. as it is equally under unfavourable weather or traffic conditions (precipitation, slipperiness, roadworks in progress). The 200% level will be employed relatively infrequently and in particular for special traffic and weather conditions (for example during rain when traffic volumes are high) for fog or in the case of serious accidents.

This preliminary switching schedule was employed in the test, during which its effect on driving behaviour was examined. The results demonstrated that the normal level of illumination resulted in minor adaptation of behaviour: average speeds increased somewhat (ca. 0.7 km/h) and the number of critical situations (short time headways, short TTCs) increased by a maximum of 1%. Taking into account also the positive effect of conventional lighting on traffic safety known from the literature, no negative effect on traffic safety is anticipated from these adaptations of behaviour.

Differences between 100% and 200% were not reflected in driving behaviour for the combination of high traffic volume and precipitation. Other situations for which the preliminary switching schedule prescribed are relatively rare and the benefit of a higher level of illumination in such situations is considered to be limited.

An inquiry among motorists' showed that the concept of dynamic illumination of motor ways was highly supported. There is absolutely no evidence to support the contention that the reduced level of illumination will under favourable circumstances be perceived as being too low.

A cost-benefits analysis was addressed to the relationship between the installation costs of DYNO (20-100-200) for the pilot location and the energy and environmental costs (CO_2 emissions from the power station). It emerged from this that for the system from the pilot project both the installation costs and the energy and environmental costs were higher than for a conventional installation. This system will therefore be unable to recover its investment on the basis of energy and environmental costs.

When the DYNO system is equipped only with the reduced and normal lighting levels, the installation costs will still be higher than for a conventional installation, but the energy and environmental costs will be lower than for a conventional installation. Due to this the system can in principle recover its investment on the basis of energy and environmental costs. This is in line with the government's policy of reducing CO_2 emissions. The payback period will depend strongly on the local situation and the tariff structure in which the system is employed.

When installing or replacing lighting along motorways t, the recommendation is to consider employing a DYNO 20-100 system instead of conventional illumination. The reduced level used for this should be 0.2 cd/m^2 and the normal level 0.7 to 1.0 cd/m^2 (corresponding to the level that would have been selected for the road section in question for conventional lighting).

The proposal for the final switching schedule is that in darkness the normal level should be switched on, except in the case of favourable weather conditions and low traffic volume: under those circumstances the reduced level will be switched on. The switching criterion proposed for transition from the normal to the low level is a volume of 800, and for the transition from the reduced to the normal level a volume of 1100 vehicles per hour per traffic lane.

1 Introduction

1.1 General

Due to increasing traffic volume more and more Dutch motorways are being illuminated. Until now a switching schedule has been employed that operates the lighting in a binary mode: the lighting is off during daylight hours and is switched on at a fixed level of luminance (approximately 1 cd/m^2) when it turns dark.

This level of lighting is believed to be necessary for particular levels of traffic volume and for certain weather conditions. This implies that it is wasteful for the lighting to remain on all-night at full strength. Perhaps under specific, favourable circumstances a reduced level of illumination might be sufficient. On the other hand specific situations may arise where an even higher level of illumination than the present is desirable (for example extreme levels of traffic volume, extremely bad weather or roadworks).

From this line of thought came the idea to introduce dynamic switching of illumination of motorway. The intention with this is to provide under all circumstances a level of illumination that is adequate for the traffic and weather conditions, without illuminating the road unnecessarily brightly (Folles, 1993).

The Ministry of Transport, Public Works and Water Management is giving consideration to equipping the entire principal motorway network with this type of dynamic public lighting (DYNO). Before proceeding with this, a trial has been conducted in practice with DYNO by the Ministry of Transport, Public Works and Water Management, Transport Research Centre on the A12 motorway.

This cover report provides an account of the DYNO trial. Chapter 2 describes the practical realization of switched illumination of motorways, the basis of a preliminary switching schedule and the structure of the evaluation. Chapter 3 then goes on to present the results of the trial with respect to the traffic study (the effects on traffic behaviour, traffic performance, accidents and the perceptions of road users). In Chapter 4 the costs and benefits of a range of DYNO variants are compared. Chapter 5 sums up the conclusion of the trial and Chapter 6 provides recommendations for the future application of dynamic illumination of motorway and the switching schedule to be applied.

1.2 Background

The policy adopted by the Ministry of Transport, Public Works and Water Management with respect to illumination of motorways between 1970 and 1990 was based on a number of core documents.

These include:
- The "Recommendations for Illumination of motorways" of the NSVV from 1974, revised in 1977 (Nederlandse Stichting voor Verlichtingskunde [Dutch Foundation for Lighting], 1974, 1977)
- The contribution of Ir. T.H. Tan to the Roads Congress "Road design and illumination in the light of traffic safety" (Tan, 1974).
- A brochure from the Stichting Voorlichting Energiebesparing Nederland [The Dutch Advisory Foundation on Energy Conservation] (SVEN, later incorporated in NOVEM): "Conservation of energy and cost-savings for illumination of motorways" (Stichting Voorlichting Energiebesparing Nederland, 1981).

It is stipulated in the first document that for lighting of motorways a road luminance of *at least* 2 cd/m^2 is required. At this level, objects on the road are clearly visible, contributing to a potential reduction of accidents at night. The NSVV thus followed the international recommendations of the Commission International de l'Eclairage (CIE; e.g. CIE, 1973). Under pressure of the energy crisis in the nineteen-seventies the "at least" was altered in the 1977 edition to "equal to".

Within the Ministry of Transport, Public Works and Water Management there were serious reservations with regard to the lighting level recommended by NSVV. Due to the limited budgets the costs always had to be weighed against the benefits. Investigation conducted on a limited scale suggested that reduced levels could also provide excellent road illumination with a similar reduction in the number of accidents. On this basis Tan presented in 1974 a proposal in which for motorways a value of 1 cd/m^2 was stipulated for road luminance. This value was thereafter adopted by the Ministry of Transport, Public Works and Water Management as a norm.

The policy adopted by the Ministry of Transport, Public Works and Water Management was further supported by a SVEN publication. This brochure, designed to provide an impetus to limiting energy consumption, contained among other items proposals for the lighting levels on motorways. The values stipulated ranged from 0.6 to 1 cd/m^2, depending on the situation. A major difference from the preceding documents was that this time new values were referred to instead of application values.

The industry had its doubts about the policy that the Ministry of Transport, Public Works and Water Management had adopted. It would seem that The Netherlands were internationally seriously out of line. A decision was therefore taken in 1986 in consultation with the central governing body of the Ministry of Transport, Public Works and Water Management and Philips to conduct a study tour to compare Dutch policy with that adopted by several other countries (Ministry of Transport, Public Works and Water Management - Philips Nederland, 1986). This study noted in its conclusions that there were wide discrepancies among the various countries in the lighting levels adopted, and that The Netherlands fell in this respect into a very low category. For this reason, besides many other, recommendations were made to carry out further investigation, especially to acquire more knowledge about the effects of lighting levels on traffic safety.

In an evaluation session between The Ministry of Transport, Public Works and Water Management and Philips the following was recorded under point 5 in the report on 20 June 1987:
"It would be worth while to incorporate the knowledge that has been assembled into a joint demonstration project. In this, new techniques and insights should be applied, also those from outside the field of road lighting. New techniques such as dimming, adapting the level to the traffic volume, weather conditions and energy conservation etc. could merit consideration. Types of lighting other than the traditional (low or in road surface) could be examined. (...) Philips is prepared to conduct such a project on a non-profit basis."

This agreement led finally to the pilot project for dynamic road lighting (DYNO). This international orientation has likewise shown that switched lighting can also be applied readily in a number of other countries (Directorate-General for Public Works and Water Management-Philips Nederland, 1986).

1.3 Objective of the project

The objective of the DYNO pilot project is to examine by means of a field trial under which circumstances, which level of lighting can be applied responsibly with respect to behaviour, safety and perception and how a lighting system of that type operates in practice in terms of energy consumption, maintenance and costs.

The objectives of the DYNO concept have been formulated concretely in terms of:
- safety
- utilization
- energy savings
- environment
- management and maintenance

1.4 Project design

An organogram of the project is depicted in Figure 1. The project management is vested with the Ministry of Transport, Public Works and Water Management's Transport Research Centre. The project was phased as follows:
- Phase 1 Road scene analysis and literature research
- Phase 2 The definition of a preliminary switching schedule
- Phase 3 Investigation of the traffic process
- Phase 4 The preparation of a collation/recommendation

TNO-HFRI was involved in the planning and evaluation of the trial in practice. Involved in the execution of the trial were Volker Stevin Rail & Traffic and the Royal Dutch Meteorogical Institute (KNMI) as suppliers of data. The Stichting Wetenschappelijk Onderzoek Verkeersveiligheid (SWOV) [Institute for Road Safety Research] made an inventory of accident statistics. Furthermore, the Delft University of Technology (TU Delft) examined the effects of illumination of motorways on the capacity and on the traffic costs-benefits. Involved in the technical realization were the Directorate South Holland and the Service Group Leiden of the

Ministry of Transport, Public Works and Water Management. Hogenboom Spijkenisse B.V. was the main contractor for the installing of the system. The dimmable lamps and the light fixture were provided by Philips Nederland Licht B.V., and Poort Handels- en Ingenieursbureau B.V. was responsible for the design and supply of the power supply, light regulation and control system.

On commencement of the project a guidance group was instituted that assessed the project results.

Figure 1
Organogram of the DYNO project.

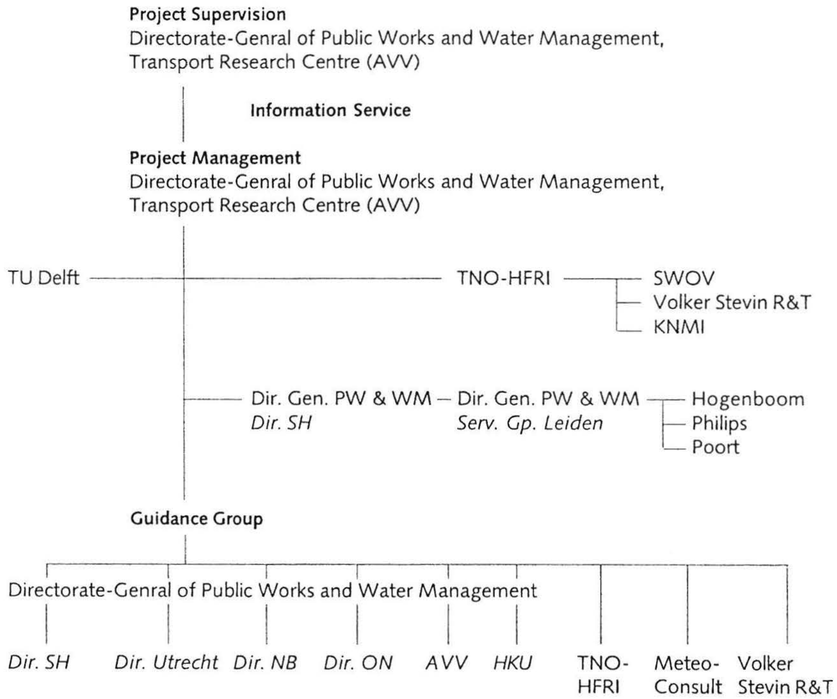
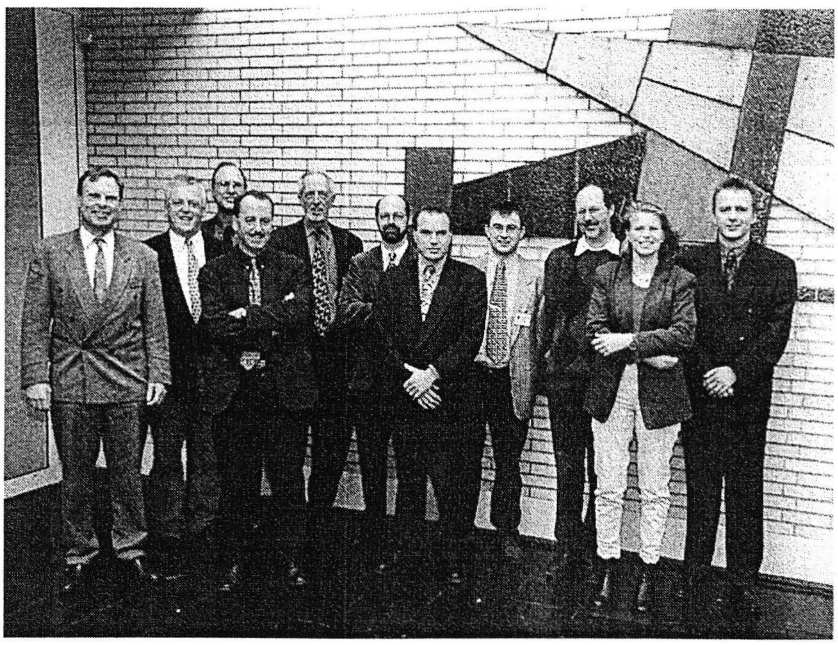


Photo
Guidance Group of Dyno

The composition of the steering committee was at the time of this report as follows (from left to right):
[2] E. Folles (chairman),
Mrs L.R. Spiekman (secretary)
[9] T.D.J. van den Brink,
W.J.M. Traag,
[3] G.van Kekem,
A.den Hollander,
[6] D. Brevoord,
[10] Mrs J.Y. IJsselstijn,
[8] A.C.C.M. Adams,
Mrs N. Nazmi,
[1] F.A.J. van Waes,
M. Noort,
[4] A.R.A. van der Horst,
[11] J.H. Hogema,

At an earlier stage the following persons were part of the steering committee:
[7] N.A. Kaptein,
[5] B.M.A. Uiterwaal,
P.J. van der Veen,
Photo: Steering committee DYNO pilot



2 Structure of the investigation

2.1 Design of the pilot system

2.1.1 Pilot location

The pilot location on which DYNO was initially installed was on the southern and northern carriageway of the A12, roughly speaking from the Gouwe Aquaduct (km 30.6) to past the connection Nieuwerbrug (km 41.5). The installation was later extended to the east to km 44.8 (see Figure 2), yielding a test section of circa 14 kilometers. This section of the A12 was hitherto unlit.

The entire road section is subject to a speed limit of 120 km/u. The road consists of two carriageways separated by a (very broad) central reservation (see Figure 3. Each carriageway consists of three traffic lanes and hard shoulder. The largest part of the southern carriageway is surfaced with normal (i.e. not porous) asphalt. The traffic volume on the control section amounted in 1995 to circa 210.000 motor vehicles per twenty-four hour periods (working days, see Directorate-General for Public Works and Water Management's Transport Research Centre 1995).

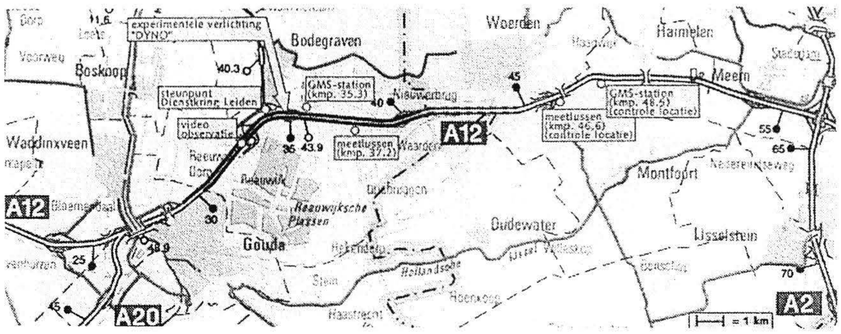


Figure 2
Overview of the control section with dynamic illumination (DYNO).

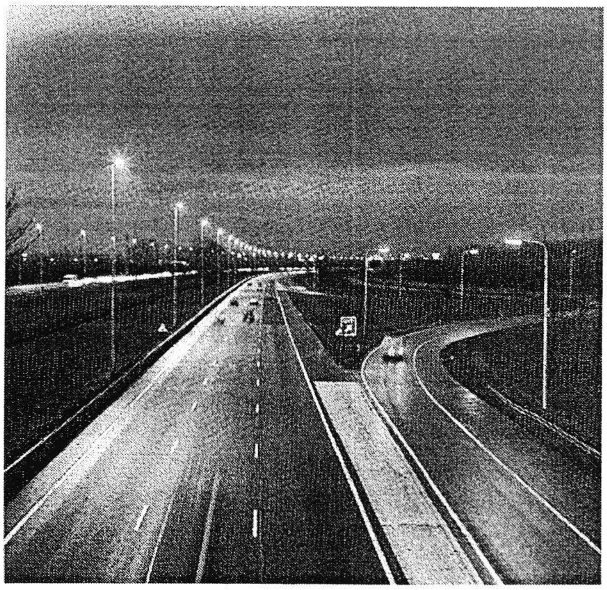


Figure 3
Photograph of road situation on the control section (with DYNO).

2.1.2 Preliminary switching schedule

As first step a literature search was undertaken to determine which elements of the road environment are visually critical when driving on motorways (Kaptein, Alferdinck & Van der Horst, 1995). It was on the basis of this information to determine to what extent the driving task differs between illuminated and unlit roads. *A road scene* of the control section of the A12 motorway was then carried out to determine the expected effects of road illumination on the driving task.

Based on the literature study and the road scene analysis, a *preliminary switching schedule* was prepared (Alferdinck, Kaptein & Van der Horst, 1996). The system design adopted an installation with four switching levels.

- off,
- a normal level (1 cd/m^2, corresponding to the most usual value for conventional illumination),
- a reduced level (0.2 cd/m^2), and
- an increased level (2 cd/m^2).

These levels were applied in the preliminary switching schedule as follows:

- When the natural light had a horizontal luminance of less than 40 lx, a low lighting level was switched on. In the event of special circumstances, an increased level of illumination was switched on, according to the following conditions:
- For high traffic volumes a normal level of illumination applied. This was switched on for more than 1000 and switched off for fewer than 600 vehicles per hour per traffic lane. This hysteresis mechanism is included to avoid undesirably frequent switching in the event of fluctuating traffic volume. An attendant advantage for the evaluation study was that within this hysteresis range both the reduced and the normal switching level were represented.
- During precipitation normal level of illumination was switched on.
- During fog (visibility less than 140 m) an increased level of illumination was switched on (both during daylight hours and after dark).
- During work-in-progress (WIP) a normal and for serious accidents an increased level of illumination is recommended.
- For very slippery roads, due to persistent black ice and heavy snowfall, an increased level of illumination was switched on.
- For combinations of special traffic and weather conditions an increased level of illumination was engaged.

These switching criteria are summarised in Table 1.

Table 1
Overview of the preliminary switching schedule. For each combination of weather condition, traffic volume and level of illumination the table states whether illumination was provided and if so which level of illumination was applied (reduced = 20%, normal =100%, increased is 200% relative to conventional illumination).

Weatherconditions	Daylight	Darkness		
		Not busy	Busy, congestion,WIP	Accidents
Good	None	Low	Normal	High
Precipitation	None	Normal	High	High
Slipperiness	None	High	High	High
Fog	High	High	High	High

2.1.3 Technical realization

A monitoring and control centre for the DYNO system was placed in the building of the district office of the Service Group Leiden in Bodegraven (see Figure 2). DYNO's process control (Folles & Poort, 1997) is based on data that are obtained from the measurement points for traffic data (the so-called census point), and on information from an weather station (GMS), see Figure 2 and Figure 4.
The IRS station provides besides existing information such as slipperiness and temperature, additional information on visibility, precipitation and wind velocity.

The required switching levels is determined in the centre. This is transmitted digitally from the centre to distribution and control stations located along the road (Figure 4).

Communications between the central computer and the regulation installation were provided by a control system for illumination with feedback supplied by GeoSys GmbH of Leipzig. Every 5 minutes (adjustable) all stations are checked for connection, status, errors and power uptake. Errors are reported immediately on a monitor and on a printer.

The control units in the switchboxes translate the digital signal into switching commands and/or report back their status. The controllers are set by means of a freely programmable Programmable Logic Controller (PLC) operated by the GeoSys management system. The switching commands are transmitted by relays to the switching installation; the regulators can be operated entirely independent of one another. The luminous flux of the lamps was adjusted using 10 WA light regulators supplied by the manufacturer INTELUX of Staad, Switzerland.

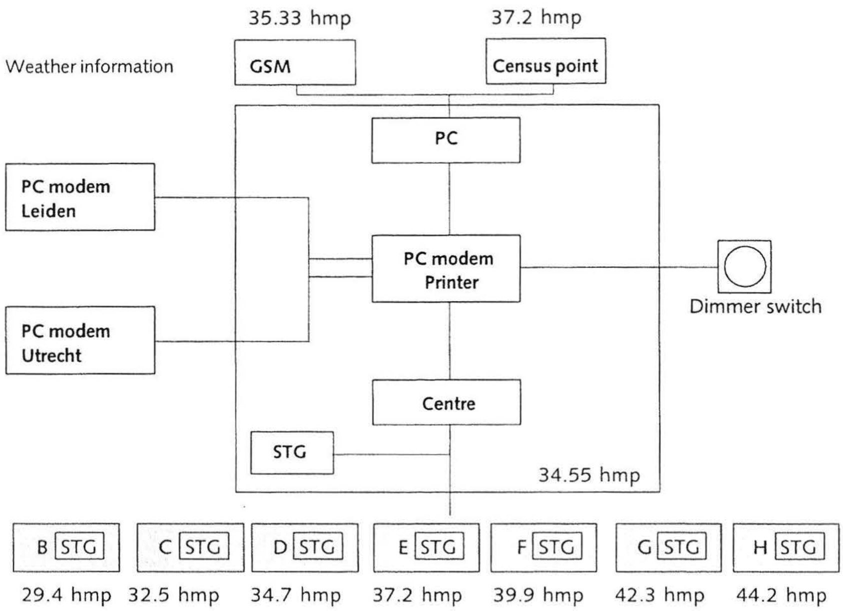
In the event of failure of the PC, control and/or monitoring centre, communications between centre and substation, PLC and/or control unit the level of illumination is switched by the switching clock (BSU by GeoSys) to 100%. The BSU, in which a calendar for one entire year has been programmed, then takes over control from the controller. This guarantees that the lighting is always engaged. This means that a control system has been realized with the largest possible freedom in adjusting parameters and the greatest certainty that the road-lighting will remain on in the event of errors.

In order to attain the lighting levels required a high-pressure sodium lamp, type SON-T plus 400W was used. A lamp of this type can be continuously controlled from 5% to 100% of its full power.

The height of the masts is 15 m, and they are set at intervals of 50 m. The masts are set on one side of the road (left). The lighting fixture is Philips type SGS 306 400T. The lamp cover protrudes for this type from under the protective section of the lamp compartment, causing light to radiate laterally as well. This means that the lamps can be discerned by road users over considerable distances ('guidance effect').

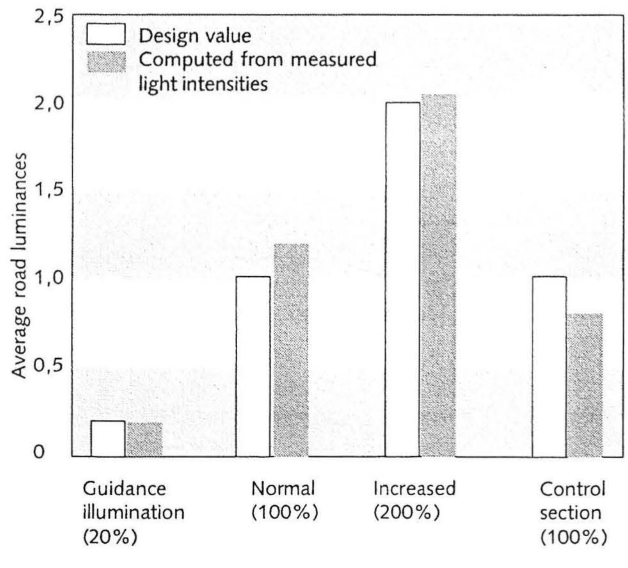
The desired values of the emission of the SON-T lighting was adjusted in advance on the INTELUX regulators and converters. The power consumption was, depending on the cutout, also reduced. Power consumption at the lowest level of illumination is a mere 20% of the normal installed power for a nominal luminance of 1 cd/m^2 (100%). The power consumption for the 100% level is comparable to the installed power of an equivalent non-regulated installation with SON-T 250W lamps.

Figure 4
Schematic representation of DYNO's process control.



Limited light intensity measurements were conducted to determine whether the levels of illumination matched the design values (Hogema & Kaptein, 1998). The method adopted was a simplified version of the NSVV method (Nederlandse Stichting voor Verlichtingskunde 1990) [Dutch Foundation for Lighting Engineering]. Using a lux meter the horizontal light intensity was measured in the test section (km 37.2), the system being switched manually for the purpose of the measurements. Measurements were also conducted in the control section (see Paragraph 2.2) with normal road-lighting (km 47.6). Measurements were conducted adjacent to and between the light sources, on both sides of

Figure 5
Average road luminances (computed from measured light intensities), compared with design values.



the left-hand traffic lane and on an imaginary line 3.6 m to the left of the left-hand traffic lane. The luminances of the road were then computed by dividing the average horizontal light intensity by the factor 11.9 (Alferdinck, Kaptein & Van der Horst, 1996). In Figure 5 these (average) road luminances are compared with the design luminances.

The luminances for the switching levels 20% and 200% correspond reasonably with the design luminances. The luminance for the normal illumination level in the control section is too high by a factor of 0.2 and in experimental section this luminance is too low by a factor of 0.2 relative to the DYNO design value of 1.0 cd/m^2.
As standard for the *uniformity* the so-called absolute uniformity was taken. This is computed by dividing the minimum light intensity by the average light intensity (Nederlandse Stichting voor Verlichtingskunde, 1990) [Dutch Foundation for Lighting Engineering]. For the control section the uniformity was 0.58 (switching position 20%) and 0.57 (switching position 100% or 200%) respectively and for the experimental section 0.55. These values are substantially in excess of the value of 0.4 recommended by the Nederlandse Stichting voor Verlichtingskunde (1990).

2.2 Structure of the evaluation study

2.2.1 Traffic study

On the basis of measurements carried out during the trial comparisons were made of various aspects of traffic behaviour with standard road-lighting and with dynamic road-lighting (Hogema & Kaptein, 1998). The structure of the evaluation study was as follows:
- a nil period (without road-lighting on the test section: January 1996 to March 1996),
- a before period (normal level of illumination - 100%: December 1996 to January 1997)
- an after period (dynamic level of illumination 20-100-200%: February and March 1997, December 1997 to March 1998).

This was accompanied in all cases by a complementary set of investigations.

Loop detector data were used to investigate how the speed and car-following behaviour of distance of drivers is influenced by the level of road-lighting, taking into account other factors that influence driving tasks (such as precipitation, traffic volume etc.) During all measurement periods continuous loop detector data were gathered at individual vehicle level at two locations on the A12: in the DYNO control section and at a control location with conventional road-lighting (see Figure 2). In the analyses various additional data records were used (including ice reporting systems, hourly visual observations, road restrictions etc.)

Using *video-analyses* an investigation was conducted into whether the type of road-lighting affected the incidence of critical encounters (conflict situations). It was specifically anticipated that such encounters would occur where traffic merged, as a result of the relatively large difference in speed between the merging traffic and the traffic on the main carriageway. The installation of adequate (switching) illumination of the main carriageway might enable this merging to proceed more smoothly.

Recordings were made and analyzed of the traffic situation at the level of the slip road at Reeuwijk (northerly carriageway). For each passing vehicle the following measures were determined: the speed, the time of passing, the category of vehicle (car, truck, etc.) and the lateral position (lane, slip road or carrying out a merging manoeuvre).

A field experiment with an *instrumented vehicle* rendered it possible to examine (besides speed and (car-) following behaviour) whether the type of road-lighting effected driving behaviour. For this instrumented automobile "ICACAD" (Instrumented CAr for Computer Assisted Driving) was employed. This vehicle was equipped with measurement instruments enabling the behaviour of the driver to be recorded in detail. Each measurement session began after the evening rush hour. The experimental section included both the DYNO control section as well as a experimental section with conventional road-lighting.

For the rest TNO-HFRI carried out a *perception investigation*. This examined the attitude of road users to driving in the dark, with conventional road-lighting and with dynamic road-lighting. The road users were also asked how they had experienced the control section.

In order to form an impression of the incidence of accidents in the trail section the SWOV inventoried the nil period in terms of *accident statistics*.

2.2.2 Cost-benefit analysis

Under contract with the instructions of the Ministry of Transport, Public Works and Water Management, Transport Research Centre, INTERSEC carried out a cost-benefit analysis (Bruinsma, 1998) in which the following variants were assessed:
- conventional lighting
- dynamic lighting in which only the reduced and the normal levels can be switched (DYNO 20-100)
- dynamic lighting of the type employed in the trial (DYNO 20-100-200)

This analysis was restricted to the following aspects:
- installation costs
- energy costs
- associated environmental costs (specifically CO_2 emissions from the power station).

In order to make a true comparison between the three variants the analysis was conducted with the situation of the control section as basis. It is immediately obvious that the costs at other locations will turn out to be lower. Just to mention one example: because of the broad central reservation on the control section two single rows of masts are required, while in many other situations a double-sided installation can be employed.

Besides INTERSEC's cost-benefit analysis, TU-Delft carried out a traffic-oriented cost-benefit analysis (Winkel, 1998). Winkel distinguished in his masterthesis various alternatives (no lighting; conventional lighting; DYNO with one fixed level of 20%, 100% or 200%; DYNO 20-100; DYNO 20-100-200; DYNO 100-200). Then two examples of large-scale application of these alternatives were elaborated. In the calculations account was taken of installation costs, energy costs, environmental stress, operating costs and traffic safety. For further information on these analyses and the results, the reader is referred to the report (Winkel, 1998).

In INTERSEC's cost-benefit analysis the calculations were based on the road section of 14 km where DYNO has currently been realized. The design of the conventional and the DYNO 20-100 system were predicated on an optimum design: masts with an 18 metre light source height (instead of the 15 metre for DYNO 20-100-200), a larger distance of separation between masts, and SON-T plus 250W lamps. All prices are net of VAT.

First of all the *installation costs* for the present DYNO system were determined and a calculation was made of what the installation costs would have been for the conventional installation of a DYNO 20-100 system.

Then a determination was made from the log files of the DYNO control system of the amount of time that the road-lighting had been on and at which level (20%, 100% or 200%) for the period from March 1997 to February 1998. From this the theoretical *power consumption* for a conventional lighting installation and that of a DYNO-20-100-system were computed. On the basis of the theoretical power connected the *energy consumed* was computed for each variant.

The energy consumption was also used to compute the environmental costs due to CO_2 emissions from the power station. This was done using the method adopted by Winkel (1998), that amounts to 6.93 cent of cost per kWh energy consumption.

Finally, on the basis of the energy consumption a calculation was made of what the energy costs would be for the three distinct variants. The energy costs are made up of 2 components.
- The hours peak/reduced tariff for the energy consumed. A daytime tariff (07:00 - 23:00 hour) and a nighttime tariff (23:00 - 07:00 hour) were taken into account. These tariffs varied somewhat from month to month; the averages were 11.9 and 8.3 cent respectively per kWh. The tariffs are not the same for all power suppliers; naturally a different tariff will effect the results of the cost-benefit analysis.
- The KW monthly levy. This is settled on the basis of the maximum power temporarily engaged during a single month.

This study does not include the costs for *management and maintenance*. This is due to there being insufficient information available for the costs already incurred and because the period covered by the study (1 year) is not significant enough for the total maintenance over the lifetime of the system (the anticipated lifetime of for example the lamps is circa two years).

3 Traffic study

3.1 Traffic characteristics

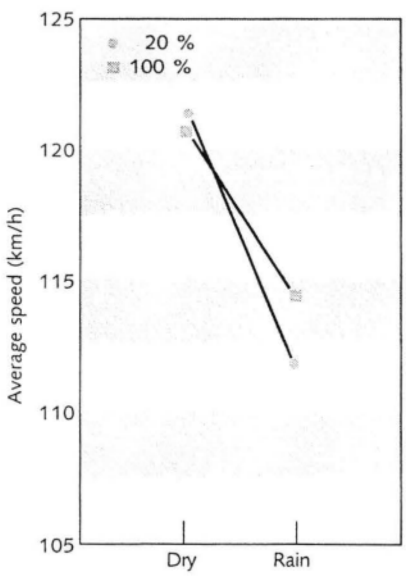
3.1.1 Loop detector data

The most unmistable effect of road-lighting on driving task is a moderate increase in average speed (1 B 2 km/u). In addition to that the standard deviation of the speed seems to increase slightly.

With respect to time headway between vehicles the results demonstrate that for the DYNO-switching levels 100% and 200% there is a slight increase of the percentage of time headway < 1 s. From analyses of the percentages TTCs (< 5 s, 10 s, 15 s respectively) there appeared to be a light increase of these variables when road-lighting was employed (irrespective of switching position).

Rain leads on an unlit road to a clear reduction of traffic speed (by ca. 5 to 10 km/h). A level of illumination of 100% results during rain in an increase of speed of ca. 3 km/h relative to the speed on an unlit road during rain. During dry weather, the speed at 20% illumination is closer to that at 100% illumination, but during rain the speed at 20% illumination is closer to that on an unlit road (see Figure 6).

Figure 6
Average speed as function of switching level and precipitation.



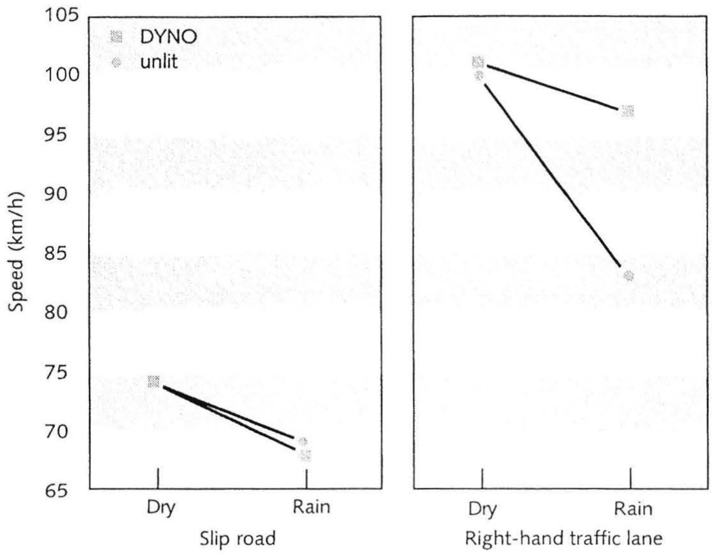
No differences were detected in driving behaviour between illumination levels of 100% and 200%.

3.1.2 Video observation

As anticipated the results of the video analysis showed that there was a substantial difference in speed between merging traffic and traffic on the main carriageway. Road-lighting however plays no part in reducing this difference.

This is illustrated in Figure 7. On the slip road there was no difference between the unlit situation and that with dynamic illumination, whether it was raining or not. On the right-hand traffic lane this was the case for dry weather, but during rain traffic was slower without road-lighting than with dynamic road-lighting.

Figure 7
Average speed as a function of illumination, precipitation and lateral position.



3.1.3 Instrumented vehicle

Statistical analyses were conducted on the average speed, the average time headway and the steering effort (percentage of high frequent steering activity: High Frequency Area (HFA).

The analyses demonstrated that specifically during rain and without illumination driving was slower, and fewer short time headways were greater than with conventional road-lighting.

From the analysis of the HFA it transpired that the difference between the two road sections was approximately the same for wet and dry weather during the various measurement periods. The only clear exception was during rain in the nil period: after dark and in the absence of road-lighting there was a relatively high workload during rain.

3.2 Accidents

The SWOV conducted an accident analysis for the nil period. The number of accidents from the before period on the control section may in due time be compared with those from the subsequent situation with dynamic road-lighting. The same comparison will have to be made for control purposes for another section of the same motorway, on which both during the before period and the subsequent period normal road-lighting was present.

The nil period adopted for the accident analysis embraced the period from the beginning of 1990 until the end of 1995. For a detailed review of the accident data reference is made to Poppe and Noordzij (1997). Table 2 summarizes the findings.

Table 2
Summary of accident data on experimental section (11 km) and control section (7 km) categorized by lighting situation and type of accident.

Accidents 1990 to 1995

Serious accident	**Road section**	**Number**				**Total number/km**
		Day	Twilight	Dark	Total	
With injury	Experimental section	50	6	38	94	8.5
	Control section	43	3	23	69	10
Without injury	Experimental section	454	35	161	650	59
	Control section	232	12	96	340	48

The differences in numbers of accidents between various sections of Motorway A12 were limited, although the accident pattern differed somewhat between control section and control section. On the control section the number of accidents with purely material damage was relatively high, with relatively little personal injury. This was particularly the case during the day.

It is safe to say that in the base situation the number of accidents was not particularly high. This does not lead to any prior expectation of achieving as a result of lighting conditions (with a limited trial like this) a relevant improvement. Despite that it will be necessary to compare in due course accident data from the before period with accident data from the after period, in order to determine to what extent under prevailing circumstances a reduced level of illumination or an increased traffic speed have or have not resulted in reduced traffic safety.

3.3 Traffic performance

In terms of traffic performance the behavioural effects detected (paragraph 3.1) can be described as favourable. A moderate increase of average speed for the same traffic volume, without this being accompanied by a real increase of brief intervals or TTCs suggests that road-lighting has a positive effect on capacity. In a study made by TNO Inro on the effect of (conventional) road-lighting on the capacity of road sections on motorways (carried out on the A50), no effect of road-lighting was detected on capacity (Van der Vlist & Droppert-Zilver, 1996). Later results from Van Goeverden and Botma (1998) suggest however that lighting has an effect on capacity. They conducted two studies, specifically on the A50 and on the A12. For the latter study they used data from the DYNO study (only periods with favourable weather conditions and switching level 100%). Their tentative conclusion was that road-lighting appeared to have a positive effect on capacity (magnitude of effect: at the most a few percent).
Possible causes of the discrepancy between these two studies may be the different methodologies for capacity assessment and the fact that the TNO study employed a smaller data set. Moreover the quality of traffic performance should not be regarded simply in terms of capacity; a more constant and stable traffic flow at lower volumes can be equally advantageous.

The conclusion may be derived that DYNO illumination will nor differ from conventional road-lighting in its effect on capacity. After all, when the volume is high the switching schedule prescribes 100% (which is precisely the same level of illumination as for conventional lighting).

3.4 Perception

Interviews were conducted during the various measurement periods with in all cases several hundred road users on the A12, who had just driven the control section. All of these interviews were conducted after the evening rush hour and during dry weather (for which the switching schedule prescribed 20%).

The opinions as to driving in the dark were varied. A clear majority (80%) was convinced of the effectiveness of road-lighting on motorways. An even larger group (89%) believed the DYNO concept to be extremely worthwhile. The vast majority was in agreement with the idea that the level of road-lighting should be dependent on the circumstances.

Only during the nil period, there were some complaints concerning (absence of) illumination on the section just driven (23%). During the after period (with 20% illumination) there were no complaints whatever to suggest that the lighting might be inadequate.

It was striking that drivers were not always able to say whether a road section just passed was fitted with road-lighting or not. The non-standard lighting at the 20% level in particular was not always perceived as such. None of the road users reported in the afterperiod an unpleasant or unsafe level of road-lighting.

4 Cost-benefit analysis

The installation costs for the three lighting variants are stipulated in Table 3. Relative to conventional lighting, DYNO 20-100 is 37 % more expensive, and DYNO 20-100-200 63 % more expensive.

Table 3
Installation costs (NLG per km, net of VAT)

Conventional	DYNO 20-100	DYNO 20-100-200
174.000	238.000	285.000

The lighting log files demonstrate that in the period from March 1997 to February 1998 the lighting was switched on for 50% of the time. When lit, the system was engaged at the reduced level 59% of the time, at the normal level 37% of the time the normal level and the increased level at 4% of the time. For the purposes of comparison: for a normal installation a number of ca. 4,000 hours lit per year has been mentioned as rule of thumb (ca 45%).

The total power consumption per year resulting from this is given for each of the three variants in Table 4. These figures demonstrate that relative to a conventional installation the power consumption for DYNO 20-100 is 35% lower and for DYNO 20-100-200 6% lower.

Table 4
Power consumption (Mwh) for the three variants (per year, entire control section).

Conventional	DYNO 20-100	DYNO 20-100-200
482	312	453

In Table 5 the power costs and the environmental costs (CO_2 emissions) are specified. Relative to conventional lighting the power costs of DYNO 20-100 are 29% lower expensive and those of DYNO 20-100-200% 17% higher. The environmental costs for DYNO 20-100 are 35% lower and for DYNO 20-100-200 6% lower than for conventional lighting. The total power and environmental costs for DYNO 20-100 are 31% lower and for DYNO 20-100-200 8% higher than for conventional lighting.

Table 5
Power costs (NLG per year per km, net of VAT)

	Conventional	DYNO20-100	DYNO 20-100-200
Power costs: hourly tariff	2747	1797	2624
Power costs: kW monthly levy	510	510	1187
Power costs: total	3257	2308	3811
Environmental costs [1]	2076	1342	1951
Total power and environmental costs	5333	3649	5761

Note

[1] Environmental costs were computed using figures for CO_2 emitted during the generation of power. These figures were computed on the basis of an average value that was determined by the NOVEM (see Paragraph 2.2.2). The quantity emitted per kWh varies from power station to power station. This applies equally to the amounts charged for this.

It transpired that for a DYNO 20-100-200 system some profit could be realized on power *consumption* but not on power *costs*. This is a result of the costs represented by the KW monthly levy, that is based each month on the maximum engaged (momentary) power. In the 200% position the power consumption of the DYNO 20-100-200-system is 2.5 times as high as for 100% (Bruinsma, 1998). Because of this in each month in which DYNO been switched at 200% (irrespective of duration) the KW monthly levy will be too high to be able to compensate for a lower average power consumption.

Since it is also more expensive to install a DYNO 20-100-200 system than a conventional lighting system, the DYNO 20-100-200 system will be unable to recover its investment on the basis of power and environmental costs.

A DYNO 20-100 system has higher installation costs than a conventional installation but lower power and environmental costs. It follows from the data in Table 3 and Table 5 that this DYNO 20-100 system on the basis of the installation in the present pilot will have a payback period of 38 years ((238.000-174.000)/(5333-3649)).

There is insufficient insight into the structure of the costs associated with realization of the present DYNO control system (total NLG 1,060,000) to separate the once-only costs (design costs, software development etc.) from the variable costs (hardware for operational units, system elements for central control, detail design cabinets and control systems). The costs of future DYNO projects (and accordingly the payback period) will turn out more favourably than for this pilot project, but by how much cannot be stated precisely.

5 Collation of results and discussion

On 7 September 1998 TNO-HFRI organized a workshop on the definitive DYNO switching schedule (Hogema & Van der Horst, 1998a). At this workshop an overview was presented of the structure and results of the evaluation study, and the questions arising from these were discussed. The results of the study, of the workshop and the cost-benefit analysis form the basis for this collation.

5.1 Should switched illumination be introduced or not

The results of the evaluation study have shown that under favourable circumstances (low traffic volume, dry weather) a reduced level of road-lighting may be adopted without any difficulties, while under different circumstances (precipitation) a normal level of road-lighting remains desirable. This demonstrates that the dynamic switching of road-lighting is in principle a worthwhile concept.

In the evaluation study of the trial no additional benefit was established for the increased level of road-lighting. It must be noted however that not all situations for which the preliminary switching schedule prescribed 200% could be evaluated (in particular fog and slippery conditions). These situations however occur infrequently and the added benefit of increased illumination is judged to be limited.

Next, the cost-benefit established that the installation costs of the DYNO-system for the pilot project in question (20-100-200) were circa 63% higher than for a conventional installation. The power consumption (and hence the environmental costs of CO_2 emissions) were somewhat lower than for a conventional installation, but due to the system of KW monthly levy, the total energy and environmental costs remained higher than for a conventional installation. It is for this reason that this system is unable to pay back its investment on the basis of power and environmental costs.

From these findings it would seem obvious to focus attention on a simpler DYNO system, specifically one without the 200% level. A DYNO 20-100 system has higher installation costs, but lower power and environmental costs than a conventional system. Within the constraints of the control section a payback period of 38 years was calculated. That seems a very long time, but there are a variety of reasons to suggest that large-scale application of DYNO 20-100 systems will have more favourable payback periods.
- The current costs include in part once-only costs necessary to this pilot project but this will not apply to larger scale applications in practice.
- Application of the concept on a larger scale will reduce the contribution of fixed costs (such as the central DYNO equipment) per km.
- On many other sections of road it will be possible to place a double-sided lighting system (in contrast to two single rows required for the pilot project). The additional costs for a DYNO system can in this way turn out to be lower elsewhere relative to conventional systems.

- Adaptation of the threshold value of the switching schedule (see Paragraph 5.2) can result in a greater saving of power.

Other factors too can also contribute to the costs at other locations being different to those at the control section, for example different tariffs on the part of the power suppliers or future tariff amendments. Also the environmental costs incurred by the power station for its CO_2 emissions vary in quantity emitted per kWh per power station, as do the costs charged for them via the tariffs.

When making the decision for a dynamic or a conventional installation, account will have to be taken of the local situation.

5.2 Switching schedule

Table 6 reflects the proposal for a definitive switching schedule as drawn up in the workshop.

Table 6
Proposal for the definitive switching schedule.

Weather conditions	Daylight	Dark		
		Not busy	Busy, tailback	WIP,accidents
Good	None	Low	Normal	Normal
Precipitation	None	Normal	Normal	Normal
Slippery conditions	None	Normal	Normal	Normal
Fog	None	Normal	Normal	Normal

In summeary, this means that at all times when it is dark the normal level will be engaged, except during favourable weather conditions and low traffic volume: then the reduced level will be engaged.

The experimental project employed hysteresis when classifying traffic volume, with as engagement limit 1000 and as disengagement limit 600 vehicles by lane/hour. This avoided excessively frequent switching and moreover hysteresis was desirable from an evaluation standpoint. At the workshop the impression was given that for further application of DYNO both switching limits might be set at slightly higher traffic volume values and nearer to one another. A proposal was made to adopt as engagement limit 1100 and as the disengagement limit 800 vehicles per hour per traffic lane. This type of modification of the switching limits has the advantage that relatively speaking the 20% level will be engaged more often and the 100% level less often and this is advantageous for the cost-benefit ratio.

The DYNO installation has, partly due to type of lighting fixture used, a guidance effect (in other words it enables drivers to anticipate to changes in the road direction over greater distances). The DYNO switching level 20% provides qualitatively more than only guidance illumination: this switching level also seems to support to some extent guidance in situ and guidance in preview (Hogema & Van der Horst, 1998b).

On the basis of a DYNO 20-100 system the following can be said with respect to the objectives of the DYNO concept (see paragraph 1.3).
- The *power consumption* will fall sharply with the introduction of DYNO (in the pilot project: 35%).

- The *environmental stress* due to CO_2 emissions from the power station will also fall by 35%.
- The *power costs* will fall less sharply than the power consumption due to the KW monthly levy in force.
- As far as safety and performance is concerned there is no difference between DYNO 20-100 and conventional lighting. The reduced level after all will be engaged only for low traffic volumes under favourable weather conditions, in other words when traffic performance and traffic safety are not at risk. The same favourable effect on safety and performance of conventional lighting will therefore also be introduced with DYNO 20-100.
- In the areas of *control and maintenance* the pilot project has provided insufficient usable data to be able to draw conclusions.

6 Conclusions and recommendations

6.1 General

It may be concluded that dynamic switching of road-lighting along motorways is a useful concept. A DYNO system that is not only able to engage reduced (0.2 cd/m^2) and normal (1.0 cd/m^2) levels, but also an increased (2.0 cd/m^2) level turned out to be disproportionately expensive to install and operate, while the extra value of this increased level was judged to be very restricted.
A DYNO system that can provide reduced (0.2 cd/m^2) and normal (1.0 cd/m^2) levels does provide possibilities for compensating the higher systems costs by the lower power and environmental costs.

The recommendation is to consider the application of a DYNO 20-100 system instead of conventional lighting for future installation or replacement of road-lighting along motorways. This system should adopt for the reduced level 0.2 cd/m^2 and for the normal level 0.7 à 1.0 cd/m^2 (corresponding to the level of conventional lighting that would have been chosen for the road section in question).
The material from the cost-benefit analysis discussed in this cover note offers the starting points necessary to weigh the system costs against the reduced power and environmental costs for a concrete situation elsewhere.

6.2 Concrete consequences for the lighting system

To be able to switch lighting dynamically a number of new elements are required compared to conventional lighting. Where a conventional installation is relatively coarse by nature, the additional elements for a DYNO system have more of an IT character.

In the first place data retrieval will be required: the switching schedule employs traffic information (volumes and speeds) and weather conditions (precipitation, slipperiness and fog). Various options are conceivable for the method of data retrieval, varying from the special installation of sensor systems to the use of data that exist already. For traffic information for example one possibility is the Monica system (Transport Research Centre [AVV] 1998), that employs detection loops to assemble traffic data, and after processing, provides them for both static and dynamic applications. In the case of information on weather conditions these may be recovered from the ice reporting system. There are also possibilities for buying up-to-date weather information (or short-term forecasts) from meteorological organizations or agencies.

In the second place the lighting itself will have to be made capable of being switched: besides the standard level a reduced level of 0.2 cd/m^2 will have to be incorporated.

Finally the lighting installation will have to be controlled on the basis of the input data conform the switching schedule. This can for example be from a traffic centre from where it is also possible to operate the system manually. This centre will then be in communications with the roadside systems. Monitoring and manual operation of a DYNO system must be feasible in a user-friendly fashion. Procedures for the manual operation of the system must be such that it does not remain unnecessarily engaged at an increased level.

References

AVV (1998). *Monica - Dynamic and static traffic information within easy reach* (brochure). Rotterdam: Adviesdienst Verkeer en Vervoer [Transport Research Centre].

Bruinsma, J. (1998). *Cost-benefit analysis DYNO. Investments costs versus power and environmental costs* (Document no. P1311V&V_JB_9801). Zoetermeer: INTERSEC.

CIE (1973). *International recommendations for motorway lighting.* CIE Publication No. 23.

Folles, E. (1993). A new generation of road lighting. *Proceedings of Right Light,* 2nd European Conference on Energy-Efficient Lighting (pp.329-341). Arnhem: 26-29 September 1993.

Folles, E., & Poort, W. (1997). Process control for dynamic road-lighting. *Syllabus congress day 'The light in the future'!* (pages 47-51). Arnhem: Bureau Nederlandse Stichting voor Verlichtingskunde [Office of Dutch Foundation for Lighting Technology] (NSVV).

Goeverden, C.D. van, & Botma, H. (1998). *Capacity conditions infrastructure Motorways. Part-report 4: Lighting.* Faculty of Civil Engineering and Geosciences, Section Traffic Studies: University of Technology Delft.

Hogema, J.H., & Horst, A.R.A. van der (1998a). *Report workshop DYNO* (Memo TNO-HFRI 1998-M44). Soesterberg: TNO Human Factors Research Institute.

Hogema, J.H., & Horst, A.R.A. van der (1998b). *Dynamic Road-Lighting (DYNO). Phase 4: Synthesis* (Report TM-98-C065). Soesterberg: TNO Human Factors Research Institute.

Hogema, J.H., & Kaptein, N.A. (1998). *Dynamic Road-Lighting (DYNO). Phase 3: Evaluation in Practice* (Report TM-98-C038). Soesterberg: TNO Human Factors Research Institute.

Kaptein, N.A., & Hogema, J.H. (1998). *Dynamic Road-Lighting: preliminary results.* (Report TM-98-C001). Soesterberg: TNO Human Factors Research Institute.

Kaptein, N.A., Alferdinck, J.W.A.M., & Horst, A.R.A. van der (1995). *Dynamic Road-Lighting (DYNO). Phase 1: Literature study and road characteristics analysis* Report TNO-HFRI 1995 C-49). Soesterberg: TNO Human Factors Research Institute.

Nederlandse Stichting voor Verlichtingskunde (1974). *Guidelines and Recommendations for Road-Lighting.* Meppel: N.V. Noord-Nederlandse drukkerij.

Nederlandse Stichting voor Verlichtingskunde (1977) *Guidelines and Recommendations for Road-Lighting*. Meppel: N.V. Noord-Nederlandse drukkerij.

Nederlandse Stichting voor Verlichtingskunde (1990). *Recommendations for road-lighting, Section I: Quality criteria and recommended values* (1 February 1990). Arnhem: Nederlandse Stichting voor Verlichtingskunde (NSVV).

Poppe, F. & Noordzij, P. (1997). *DYNO investigation: Note on accidents in the before period.* Leidschendam: SWOV: Institute for Road Safety Research.

Ministry of Transport, Public Works and Water Management- Philips Nederland (1986). *Study Trip Road-lighting.* The Hague/Eindhoven, March 1986.

Dutch Foundation for Information on Energy Conservation (1981). *Saving on power and costs for road-lighting* (Brochure EBO 0076-81.08). Apeldoorn: SVEN.

Tan, T.H. (1974). Road-lighting in practice, *Road design and Illumination in the light of traffic safety.* Congress day 1974 of the Association for Dutch Roads Congress (pages. 139-176). The Hague.

RWS-AVV (1995). *Traffic Data Annual Report.* Rotterdam: Ministry of Transport, Public Works and Water Management's Transport Research Centre.

Vlist, M.J.M. van der, & Droppert-Zilver, M.N. (1996). *Traffic performance on the A50 without and with road-lighting* (Report INRO-VVG 1996-28). Delft: TNO Inro.

Winkel, E. (1998). *Cost-benefit analysis for dynamic road-lighting. Analysis of effects and application on the main road network.* Graduation dissertation dated. 28-11-1998. Transport Research Centre / University of Technology Delft.