# Energy efficient LED lighting solutions for reduced cost and improved road safety

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**KEYWORDS**

traffic safety, road guidance, road lighting, bad weather conditions, rain, snowfall, fog, night time driving, maintenance costs, LEDs, light-emitting diodes, poles, bollards, Sweden, Gävle-Sandviken, National Road Administration

**ABSTRACT**

In two pilot road lighting projects, alternative solutions for lighting of road junctions and roads were tested. The primary aim was to try a radically new concept for improving road safety while the total energy and maintenance-related ownership costs for the Swedish road administration were to be reduced.

The primary technology employed consisted of poles equipped with light-emitting diodes (LEDs) that served to guide the traffic rather than to illuminate the road surface. In many cases the standard overhead lighting was completely removed, or drastically reduced. Especially in bad weather conditions such as snow, heavy rain, or fog, the visual conditions for drivers were improved. In one pilot project in the area of Sandviken/Gävle, the energy consumption was reduced by 75-80 percent with the new solution. An evaluation performed by the Gävle/Sandviken University has shown a very high acceptance among drivers.

Since the system was installed (more than two years ago), no accidents have been reported from the test area. This is to be compared against a normal car accident frequency of about one accident a month prior to the new installation.

The National Swedish Road Administration in the Mid-Sweden district regards this technology, and the application of the technology, so promising that the system is now being applied along four additional road stretches which are currently experiencing many accidents. Photovoltaic (PV)-powered modules are also being tested and evaluated along one road stretch.

The Swedish National Energy Administration sponsored two pilot projects, but the National Road Administration is now implementing the system on its own merits.

**INTRODUCTION**

Today LEDs are to be found practically everywhere in various applications, mainly as indicator lights, numeric displays on consumer electronic devices or advertisement boards.

In applications that are close to illumination, LEDs have already gained a widespread use for exit signs and traffic signals, where the LEDs' long life is a very important factor for the safety and economy in maintenance. In transportation, LEDs are found in applications such as decorative lighting, dashboard backside illumination, and automotive brake lights. In railroad transportation, LEDs have been used for long distance narrow beam searchlights, as well as signals.

LEDs are also increasingly used in architectural lighting, following recent developments in new materials and production processes, which have resulted in brighter LEDs with an efficacy typically greater than that of incandescent lamps. LEDs now can produce colours throughout the visible spectrum including white light. Although the spectrum still lacks the qualities, which should make it suitable for general indoor lighting, they are useful in certain applications such as task lights and spotlights because of their small size and low weight.

*Figure 1. The road junction at night. Each pole has an active LED unit, as well as a reflective background coating.*

## BACKGROUND TO THE PILOT ROAD PROJECT

In a pilot installation in Mid-Sweden the Road Administration has been testing white LEDs mounted on poles to partly replace the traditional road lighting in a traffic junction outside the city of Sandviken.

The intentions of the project were to:

- increase traffic safety
- reduce energy consumption
- decrease maintenance cost

The project was planned in conjunction with an architectural and landscaping renovation of the traffic junction, which also included a modernisation of the lighting installation. The approach was that this modernisation should not only upgrade the lighting to today's standard but also be adapted to the environment and landscape around the traffic junction.[1]

The traffic junction has a complex and complicated geometry because of the landscape and layout of the roads. The guiding system through the traffic junction has to be well planned and clear to avoid hesitant behaviour from the drivers during day and night, especially under poor visual conditions such as heavy snowfall, rain or fog. Under such conditions, traditional lighting on high masts or poles sometimes gives very little guidance for the drivers. In some cases, drivers may even be confused by the traditional luminaires, which cause glare or other unwanted visual effects.

## FEASIBILITY STUDY

The project started with a feasibility study where a number of solutions were investigated.[2] Conventional lighting systems in masts of various heights, as well as hollow light guide systems, reflective materials and LEDs placed on low poles (or bollards) were investigated. Among the parameters for evaluation, the lighting solution's impact on traffic safety was regarded as the most important.

The study concluded that a solution with low-position, guiding light points, with light directed towards the drivers, would best satisfy the needs and requirements stipulated by the Road Administration. It also concluded that, due to the low position of the lit units, it was crucial to get the light intensity and direction of the units right. In order to meet the visual requirements, it was found that only an LED-based unit seemed feasible within the financial and other technical restrictions stipulated.

### Low placed road lighting: previous experience

Only one example of low placed road lighting was found in literature. This was an article from 1967 in The Illuminating Engineering, describing an example from the Netherlands, where low placed light was used on a bridge with frequent fog problems (a motorway bridge crossing River Lippe). Experiences from the project indicate that this solution was very much appreciated by drivers during foggy conditions, but that some drivers experienced glare in clear (night) weather conditions. "The low lighting system is primarily one that provides guidance, much as tail lights of a car ahead help maintain a driver's orientation. It is a lighting plan of relatively low cost that has proved helpful to motorists driving through fog."[3] This installation is not in use today. We have no information why this is the case.

At a later stage, we also received information about a project in the San Francisco Bay area, where low lights were tried in the 1970's on a bridge that crosses the bay. The project seems to have been a failure, however, since drivers experienced glare and the installation was removed. Information about this project is anecdotal[4], but it seems to underline our basic assumptions that glare control is crucial.

### Other benefits of the LED-based solution

The investment and life cycle cost (LCC) calculation showed that the LED installation would offer the most financially attractive solution. This was mainly because the preliminary planning showed there would be a large reduction of electricity consumption. The long life of the LEDs would also have a beneficial impact on the maintenance cost.

The result of the feasibility study—which indicated both improved traffic safety and energy efficiency—also attract-

1. Östlund, Ola, and Pärs, Harry. Summer and autumn 1998. Vägverket Region Mitt (National Road Administration, Mid-Sweden Regional Office). Personal communication at various occasions during the planning phase of this project.
2. The author of this paper was the consultant for the technical evaluation of the various lighting systems and their impact on the visual environment. The evaluation was done together with Mr Harry Pärs of the Road Administration's Mid-Sweden Regional office.
3. Anti fog lighting in Europe. Illuminating Engineering, IESNA, United States, February 1967.
4. Fernstrom, Gary, Pacific Gas & Electric, San Francisco. February 2000. Personal Communication

ed the interest of the Swedish Energy Administration (STEM). In order to expand the pilot project to more areas, the Energy Administration and the Road Administration jointly provided the financial resources.

Beside the technical evaluations and documentation it was decided that driver responses should be evaluated. This would be done during a one-year period following the installation of the system. This later part was to be carried out by the Gävle-Sandviken University.

### THE PILOT PROJECT

The project was divided into two phases:

- planning and installation
- a one year control and evaluation period, including a survey based on forms handed out to (mostly professional) drivers.

The conventional and previously installed lighting systems at the traffic junction in the first pilot project (as well as in most other junctions of similar size and type) was based on a number of 17 meter high masts carrying three to four luminaires, each equipped with a 400W high-pressure sodium (HPS) lamp providing an average illumination over the whole junction of 30 lux.

This kind of lighting system functions very well in clear weather, but, on the contrary, provides bad illumination in rainy weather, during foggy conditions or snow fall, or when dry snow is whirled up by passing cars, a phenomenon described as "snow smoke" in Swedish. The snow or water in the air will redirect light in all directions, thus creating a "visual blur" around the junction.

In this particular traffic junction, the complicated topography and road layout have caused many accidents, particularly during the bad weather conditions described above. In a typical accident, a single car has driven off the road. [5]

#### Defining poles and layout of lighting system

When the LED and pole solution had been decided on in principle, the next step in the planning was to find out the best type and configuration of the white LEDs in the unit to be mounted on the pole: How many should be used, what should the size of the unit be, what mounting geometry and what background should be chosen?

The design chosen was a low (approx. 1 m) aluminium pole with the LED unit attached on top of it. In the pole's original design, the LED unit had 10, rather narrow-beam, LEDs directed towards the oncoming traffic. The LEDs are mounted on board covered with the standard reflective film used on poles along Swedish roads, and the film thus serves as a backup if the LEDs fail. The total power of one original LED unit was approximately 3W, and the poles were designed to be lit both day *and* night. It would be better if the LED units were lit only during night and during bad daytime weather conditions. However, at that time no reliable control strategy and technology could be identified that would allow such a dynamic use of the poles. At a later project outside the city of Sundsvall, a control system to allow the poles to be lit as described above has been implemented.

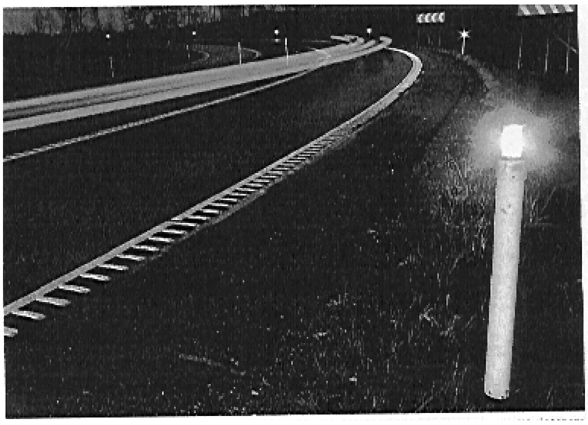

*Figure 2. The LED-units are mounted at approximately the same height as the reflective coating on a standard, non-LED pole along Swedish roads.*


*Figure 3. The original design of the LED pole. Ten white LED packages are mounted on a board covered with the same reflective film as is used in the standard poles along Swedish roads.*

When the configuration of LEDs and other details of the unit and the pole had been set, the planning of the lighting layout could start. An analysis of the traffic junction's layout focused on the location of so-called conflict points and how these could be illuminated. The conflict point was typically a junction where two roads met in a crossing or

5. Östlund, Ola and Pärs, Harry. Ibid.

*Figure 4. The redesigned LED pole with LED packages mounted behind a thick block of clear acrylic, which is integrated into the aluminium pole. Note that the number of LED packages could be reduced from ten to four due to use of higher-brightness LEDs.*

**Figures 5-12: Responses from mainly professional drivers regarding the LED pole solution.**

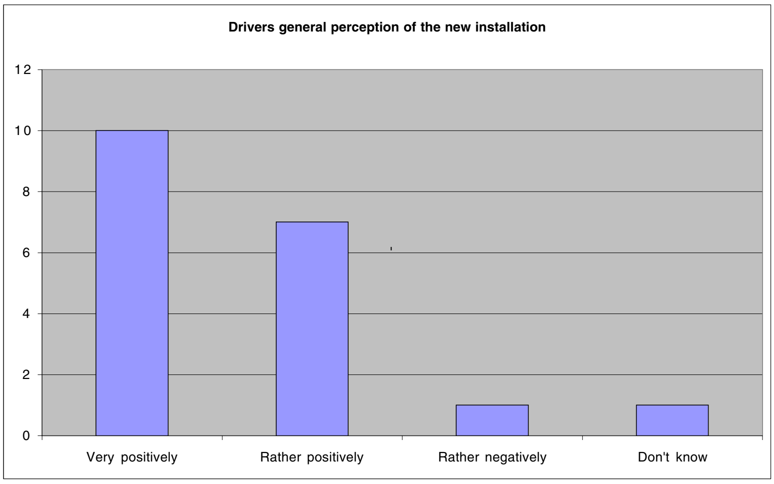


*Fig 5: 17 out of 19 drivers had a generally positive response the new solution (Seth, 2000).*

came together or parted in a fork, especially when a larger road with high-speed traffic meets a smaller one with lower-speed traffic.[6]

These conflict points were illuminated with three fixtures, each quipped with a 150W HPS lamp mounted on 10 meter high masts (compared with the previous 17-m meter masts and luminaires equipped with 400W HPS lamps). This lighting was arranged in such a way that cars coming from the right at a crossroad always had good vertical illumination on the left side of the car.

Between the conflict points, the LED poles were placed out according to the curvature of the roads and expected need of drivers' visual guidance through the traffic junction. Since no experience on this was available, this was based on a common-sense approach. The distances between the poles vary between10 and 40 meters.

The planning of the project was completed during the summer 1998 and the installation was planned to be finished before the winter season. However, because of early and extreme snowfall (more than 2 meter snow within a couple of days) the installation had to be postponed until spring 1999.

#### Stolen LED poles resulted in improved design

Immediately after the installation of the LED poles another accident hit the project. A large number of poles were destroyed and the LED fixtures were stolen. After redesigning the poles to be more burglar proof, the installation was completed again and the practical test and evaluation period could start in autumn 1999. The redesigned poles utilised only four LEDs and the power was reduced by almost the half (from approximately 3,0W to 1,5W).

### EVALUATION AND RESULTS

#### Drivers' responses

The result of the one-year evaluation period showed that the drivers felt an increased traffic safety and with few exceptions regarded this new lighting installation very positively. In the drivers' view, the new type of installation provides accurate and secure guidance through the traffic junction regardless of the weather conditions.[7] The drivers' feelings and statements are certified by the fact that during the evaluation period no accidents were reported. This is to be compared with monthly incidents before the new system was installed.

Figures 5-12 show the some of the key results of the survey, based on questionnaires filled out by mainly professional drivers. The results we have chosen to present here focuses on the general appreciation of the system, its ability to guide drivers and whether the brightness of the LED units was appropriate. The questionnaires were handed out at a petrol station and a roadway restaurant where drivers stopped after having passed the pilot installation. A total of 40 questionnaires were handed out, of which a total of 19 were returned.

The drivers were asked about the first impression (when applicable), but there is obviously no way of telling whether the drivers accumulated experience was reflected in their responses. The low number of questionnaires returned is a weakness of the study, but the results nevertheless seem conclusive.

#### Discussion on drivers' responses

The responses indicate that the chosen light intensity is right if the varying weather conditions are taken into account. Whereas some drivers seem to find it too bright during clear conditions at night, no one really seems to

6. Östlund, Ola and Pärs, Harry. Ibid.
7. Seth, Michael, 2000. Note: This report is the officially commissioned evaluation regarding drivers' responses. All information in this paper regarding the driver evaluation uses this report as the source, including diagrammes and charts.

find it too bright during bad weather conditions, except for rainy conditions during night and day when one driver found it too strong. On the contrary, in foggy and snowy conditions, some drivers' responses indicate that they would have preferred even higher light intensity.

#### No accidents

After two years of operation, no accidents had been reported from the junction. This is to be compared with a frequency of approximately one accident per month prior to the new system.[8]

#### Planning and installation costs

The cost of the planning and the installation showed a reduction of about 25% compared to the costs for a conventional lighting installation.

It was concluded that if this system would be used in larger scale the cost reduction probably could be another 15-20%. This means about half the cost of a conventional Swedish road lighting installation in a junction.

#### Maintenance costs

The maintenance costs were also heavily reduced. This was not only because of reduced energy consumption, fewer conventional lamps, lower masts and the long life of LEDs. Another important factor was the fact that traditional poles with reflective coating (always used along these types of road) have to be cleaned a couple of times during the year to keep their reflective ability. The new LED poles did not need any cleaning during the first year at all, since the reflective surface was protected.

It is still unclear how often the LED poles need cleaning, and this is currently being evaluated.

#### Energy efficiency

The installed power for the new lighting system is 2,3 kW compared to a conventional system, which would have needed about 9,0 kW according to standard design guidelines. The energy cost for the first year was reduced by 75-80% compared to a standard lighting solution.

### FURTHER DEVELOPMENTS AND PROJECTS

Since the evaluation period ended late in the year 2000, additional installations have been completed at similar traffic junctions in Sweden. In October 2001 a new installation on the highway between Sundsvall and Timrå will be completed. The length of the highway is 17 km and a part of it will be lit only with LED poles and the conventional high mast lighting be completely removed. At the traffic junctions along the high way the lighting system will be similar to the one at Sandviken described above.

Together with the National Road Administration, we are also involved in developing and testing a solar PV-based solution for the LED pole. Due to the northern latitudes of these installations, it has been difficult to configure a reliable and cost-effective system that manages to store enough

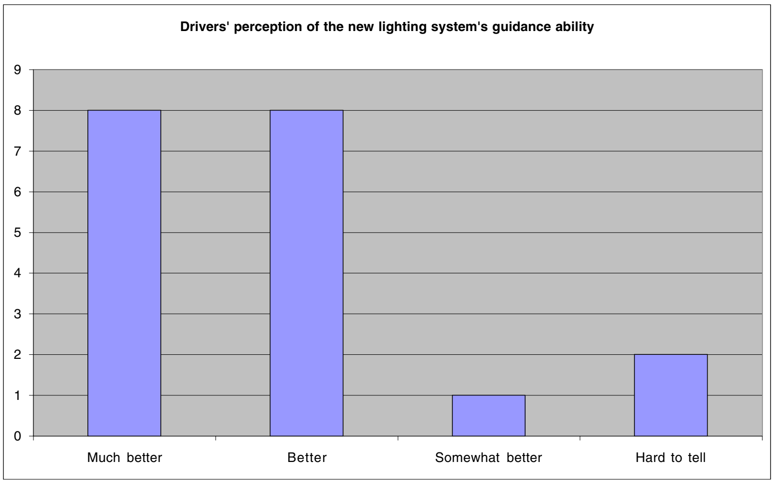


*Fig 6: 16 out of 19 drivers said that the new system's general ability to guide drivers through the junction was better or much better than the previous (standard) lighting solution's ability to guide drivers. One additional driver thought the new system was somewhat better (Seth, 2000).*

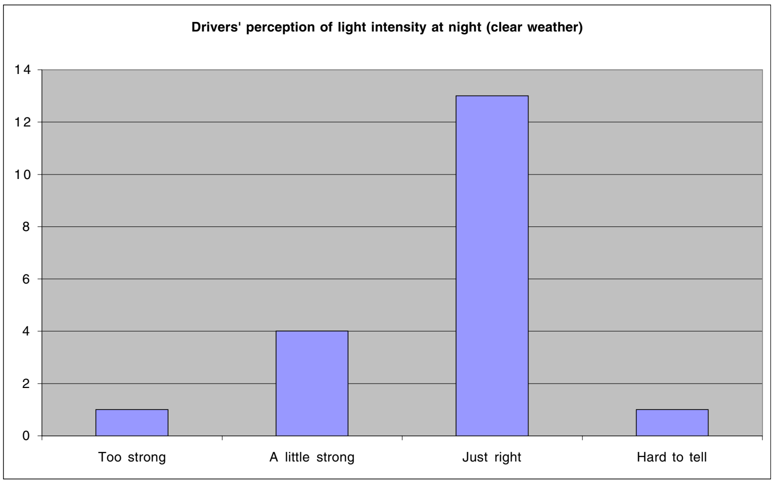


*Fig 7: At night (clear weather conditions), 13 out of 19 drivers said the light intensity of the poles was just right. Only one driver complained it was "too strong" (Seth, 2000).*

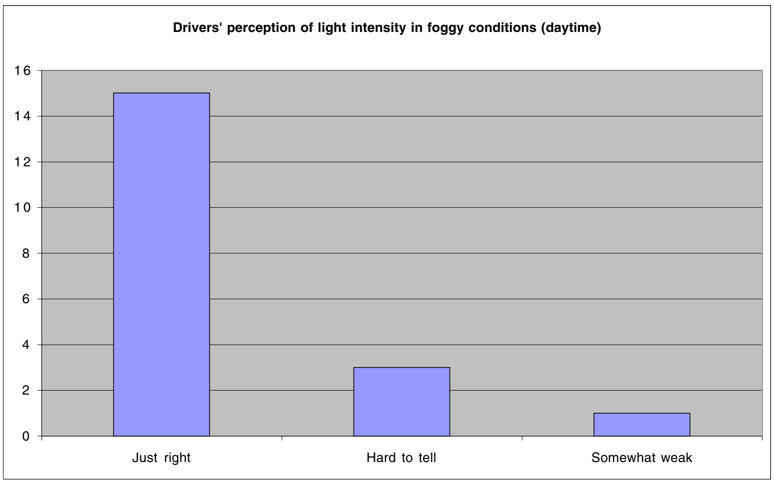


*Fig 8: In daytime foggy conditions, 15 out of 19 drivers said the light intensity of the poles was just right. Only one driver said it was "too weak" and none complained it was too bright (Seth, 2000).*

8. Pärs, Harry. November 2001. National Road Administration. Personal Communication.

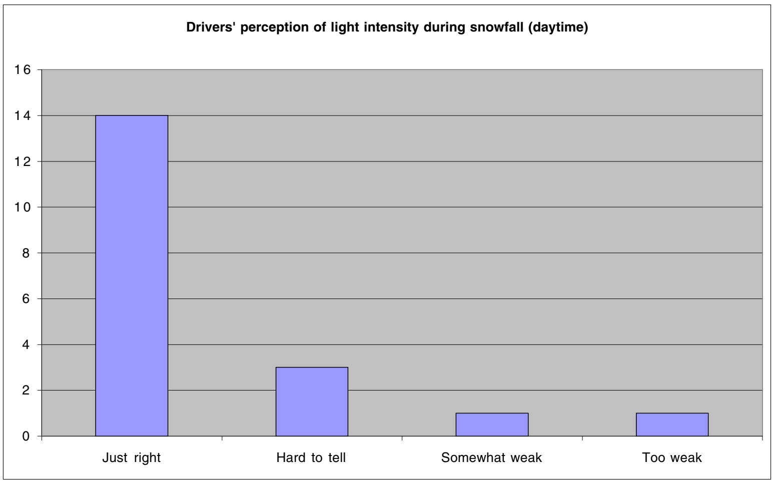


*Fig 9: During snowfall in daylight, 14 out of 19 drivers said the light intensity of the poles was just right. Only one driver complained it was "too weak" and one more said it was "somewhat weak". (Seth, 2000)*

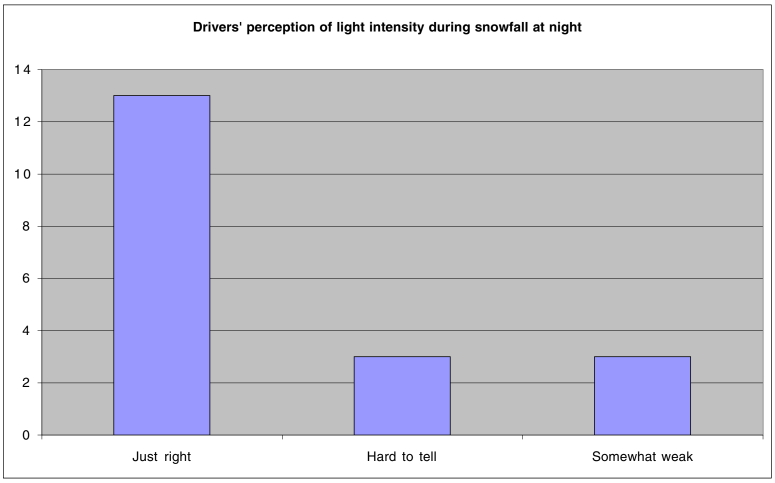


*Fig 10: During snowfall at night, 13 out of 19 drivers said the light intensity of the poles was just right. Three drivers thought it could be stronger "somewhat weak" (Seth, 2000).*

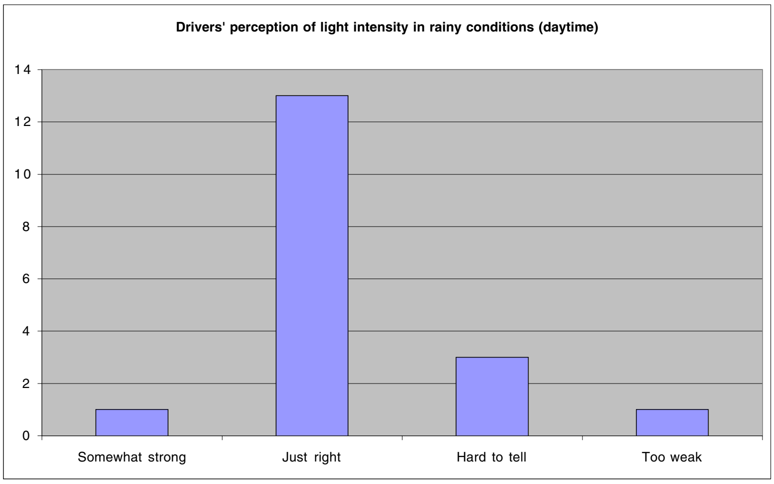


*Fig 11: In rainy conditions at daytime, 13 out of 19 drivers said the light intensity was just right. One thought it was too strong and one too weak. (Seth, 2000).*

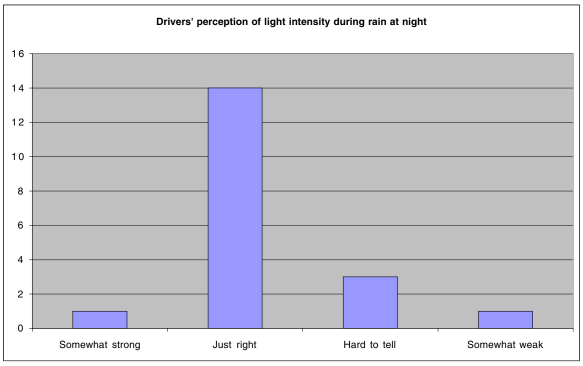


*Fig 12: In rainy conditions at night, 14 out of 19 drivers found the light intensity just right. One additional driver found it too strong and one too weak (Seth, 2000).*

energy during dark winter months, and the results of the evaluation are not yet finished.

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## PROJECT INFORMATION AND ACKNOWLEDGEMENTS

All projects described in this paper have been commissioned by the Swedish National Road Administration, Region Mid-Sweden. (Vägverket Region Mitt).

The lighting consultant has been Pelk Design Group KB, Stockholm.

The LED fixtures and poles have been developed and designed by Lars Bylund, Pelk Design Group KB and Monika Gora, Gora Art & Landscape AB.

The LED fixtures and poles have been manufactured by Deltalux AB, Sollentuna (Stockholm).

More information about the projects is presented on web sites for Swedish Road Authorities and Swedish Energy Administration.
www.vv.se/fou_exam/fou/led/index.htm