LED'S MAKE RAIL BETTER

D.W. de Bruijn, H.F.L. Frieling

Intergo BV, P.O. Box 19218, 3501 DE, Utrecht, The Netherlands
Tel. 0031 30 677 8700
debruijn@intergo.nl
frieling@intergo.nl

Abstract
This paper describes two applications of LEDs in rail: head lamps and railway signals. These light sources are traditionally equipped with candescent light bulbs but LEDs are different in their light characteristics. The driver's task needs to be considered to redesign the head lamp or signal in such a way that it performs in the same way, or better. A human factors specialist can assist in this. The benefits will outweigh the cost of the advice.
Keywords: LED, head lamps, railway signals

1. Introduction

1.1 What is so special about LEDs?
LEDs are electronic light sources with a long lifetime. In comparison with conventional candescent bulbs they use little energy. Just as in traffic signs, their application in headlamps and light signals for railways is profitable. LED rail signals will replace the conventional candescent signals with light bulbs in the near future. The same can be expected of headlamps. LEDs have many technical advantages but their light characteristics are different from those of signals and headlamps based on candescent bulbs. LED light sources have a specific beam angle as a result of their built-in lenses: this beam is approximately 14 degrees wide in most types. A typical candescent rail signal has a beam angle of 6 degrees horizontally. And LED based lights typically consist of many small light sources whereas candescent lights normally use one bulb.
Because of their typical light characteristics LED lights can't be applied without careful consideration of the task at hand. We will describe two applications in rail: rail signals and train headlamps.

1.2. Signals and the train driver task
Rail signals are very important to a train driver. They tell how to drive the train and therefore they need to be very well visible. In the Netherlands signals have three colours: red (stop), yellow (speed limits) and green (maximum speed). It may seem that they resemble traffic lights a lot, but the task of the train driver certainly is different of the car driver's task, or a pilot. For instance, rail signals must be visible from hundreds of meters because braking distances are very large. And a rail yard may have many signals at different positions. This requires a signal design in a way that drivers don't make perception errors and are not irritated.
A human factors risk inventory revealed that LED signals are rather different from candescent signals in both their normal light output and in their output when they

fail. For instance, the spectral distribution of LED light is concentrated on one wavelength, which makes it brighter than an equally powerful candescent light (Bullough e.a. 1999). Failure of a signal will result in distinct patterns of groups of LED lights. Such effects were suspected to influence the perception of rail signals and lamps.

2. Railway signal identification with LED signals

Only a few LED signals had been placed as a kind of try-out. One reason to investigate them was the complaints (at night) from train drivers: they found the new signals uncomfortably bright. We started with a risk inventory and desk research. Then a series of experiments and studies was run in cooperation with the manufacturer. This led to a new design, with reduced intensity at night but still good visible at daytime.
The new LED signal is less bright and produces light in both a narrow and a wide beam so it can be well seen from aside in for instance curves, without being too dim at long distances. Technical and methodological details can be found in separate papers (de Bruijn 2004; de Bruijn e.a. 2006).

2.1 Introduction

The wide LED beam has some advantages over the narrow conventional beam. We wanted to know: "are there any risks or unwanted effects of this wider beam of LED signals?" For instance, a wide beam would mean a -so far- inconspicuous signal now became very conspicuous and therefore changed the total 'picture' for the driver.

We found that train drivers use two different strategies to identify 'their' signal:

[1] on complex tracks, drivers rely on counting. For instance, driving on the <u>third</u> track from the right means reading the <u>third</u> signal from the right. We expect that the high visibility of LED signals could influence this strategy if signals on adjacent tracks become better visible then they would be with conventional signals.

[2] in addition, the relative brightness of signals gives a clue. The signal that is yours and is pointed most towards you, appears as the brightest. The clue is useful when is difficult to count tracks (e.g. at night). We expect that the steady high luminosity of LED signals (because of the wide beam angle) could eliminate this clue.

The use of these strategies became focus of our investigation. Most of it has been described in more detail in an earlier paper (de Bruijn e.a. 2006).

2.2. Method

It was not possible to study any effects in reality as only a few LED signals were present and test tracks were not available. Therefore a computer simulation was set up, aimed at finding trends. We varied the complexity of track situations. See figure 1. The differences between the two signal types and the effect of viewing a signal from an angle was obtained by varying the screen brightness and adding a 'halo' around the LED signals. A few drivers tested the simulation and confirmed that both conventional and LED signals looked realistic. Figure 2 gives an impression. (The difference between the first and the new type LED signals was too subtle for a screen simulation).

Three possible arrangements of signals were defined on the track layouts:
[1] all conventional candescent signals
[2] mix of conventional and LED signals
[3] all LED signals.

Subjects were 23 experienced train drivers. Drivers had to name the colour of their ‘own’ signal by pressing one of three related buttons (red/yellow/green). Reaction time (representing mental processing) and errors (right/wrong) were recorded.

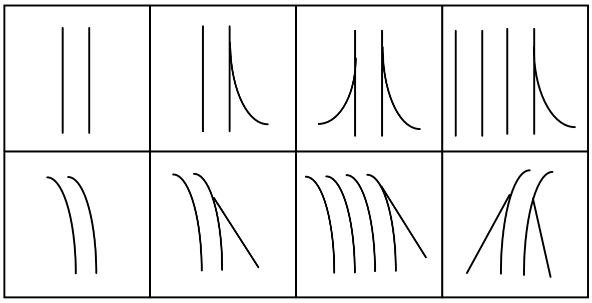

Figure 1. Experimental track layouts, straight and with curves; and with or without junctions / adjacent tracks. Drivers would always be on the main tracks.

Figure 2. A typical test image at night time.

2.3. Results
Driving at ‘day’ vs. ‘night’ makes no difference. The fewest errors are made in the condition with only traditional signals. The most errors (54% of total) occur with the LED condition. Where conventional and LED signals are mixed, the reaction time is longest.

2.4. Discussion
Apparently, LED signals had an adverse effect on errors and reaction times. However, this didn’t work out the same for mixed and LED condition. One explanation can be that in the mixed condition drivers were puzzled and more alert leading to longer reaction times. Explanation for the errors in the LED condition could be that drivers made errors in the counting clue, by counting all visible <u>signals</u> but by forgetting to include the adjacent <u>track</u> in the count. Remember that with a narrow conventional beam the signal on the adjacent track was barely visible whereas the wide LED beam is visible in a great area.

2.5. Conclusions and follow-up

The simulation suggests that LED signals can indeed cause risks or unwanted effects, especially on complex track layouts. A subsequent field investigation plus questionnaire revealed that drivers in general see an advantage in a wide beam. So this wide beam of a LED signal turned out to be an improvement if applied with caution.

This first simulation was a trend analysis and could not represent the reality. As a final step, a new and very realistic simulation has been developed. This is now used by for contractors or investigators as a tool for revealing any unwanted effects of the positioning of LED signals in complex situations.

3. LED-headlamps for trains of the Netherlands Railways

3.1 Introduction

NedTrain Fleet Management have developed LED-headlamps for trains of Netherlands Railways (NS). Intergo has advised on the Human Factors concerning the perceptual aspects of LED-headlamps: seeing, being seen and avoiding of glare.

The development of the LED headlamps consisted of several stages. The first step was a static assessment of the design by experts and train drivers. The adapted design was also first assessed in a static setting (and adjusted) before dynamic testing by train drivers. This part of the article describes the end phase in which the adapted design is tested in a dynamic setting.

LED-headlamp high beam will be used as standard according to present NS-regulations. Low beam is used in cases of potential glare (e.g. oncoming (train) drivers, passing/stopping at stations, track workers).

LED-headlamps must perform conform to the stand-still principle in relation to safety: minimally the same performance and no new problems.

3.2 Design

Dutch trains have three headlamps (2 left/right and 1 centre). All three headlamps can be switched to high beam and low beam (see Figure 3). The LED-headlamps are built into the existing fittings.

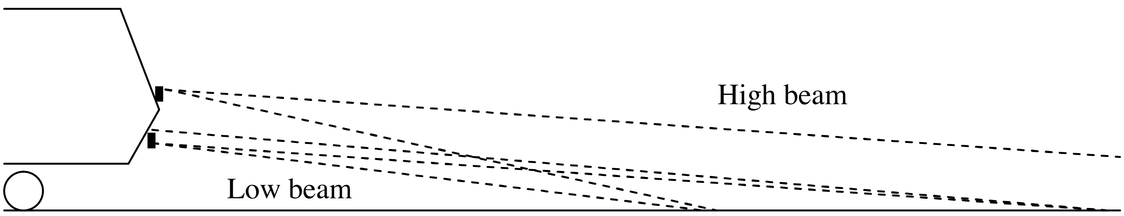

Figure 3. Relative position of high and low beam. Source NedTrain

The low and high beam are placed on two separated mounting plates with different angles. The round mounting plates consists of an outside circle plate with 2 LED-strings of 6 LEDs and an inside circle plate with 1 LED-string of also 6 LEDs. The centre of the high beam crosses the track at 150 m in front of the train (= dropping 1 centimetre per metre). The centre of the low beam is closer to the train (about 90 m).

The distribution of the luminous intensity of the beam is a compromise between seeing/being seen and (avoidance) of glare. The existing yellow light bulbs have a strong light-dark boundary. Due to a different light distribution standard LEDs have no such strong light-dark boundary so there is potentially more glare (see Figure 4).

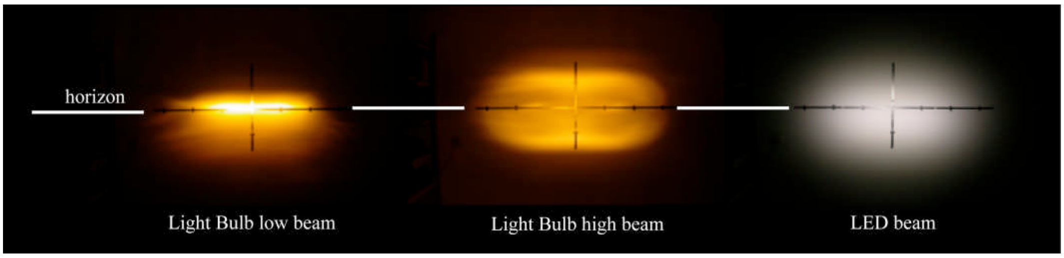

Figure 4. Luminous intensity of bulb and LED beams.

The challenge was to determine the right luminous intensity, declining angle and spreading angle of the low and high beam. Conform UIC 534 guidelines the luminous intensity of train headlamps for existing trains must be between 300 - 700 cd for the lower headlamps and between 150 – 350 cd for the upper headlamp (both specified only for the beam centre). The official guidelines are not very explicit about the relative distribution of the intensity within the beam. The following intensities are proposed from an ergonomic point of view on basis of a comparison with car headlamps:

› Being seen:
  High beam: minimal 400 – 800 cd; optimal > 2000 cd (centre)
  Low beam: minimal 400 – 800 cd (centre)
› Seeing signs:
  High beam: > 400 cd (above horizon)
  Low beam: pref. > 400 cd (above horizon)
› Avoiding glare:
  High beam: to oncoming train driver pref. < 800 cd (above horizon)
  Low beam: to oncoming train driver < 250 cd (above horizon);
  to shunter near the track < 800 cd (under horizon)

The luminous intensity of tested LED (white) of the high beam was 1900 cd and of the low beam 700 cd (in centre). The luminous intensity of the original light bulbs (yellow) was respectively 2200 cd and 500 cd (in centre).

3.3 Method

The dynamic tests of the LED headlamps were held January 2008 with train type SGMm on the track between Alkmaar and Schagen. The circumstances were fine (dry and clear sky). An impression is shown in Figure 5. The headlamps appear brighter on the pictures than in the real world. The LEDs were mounted on one side and the original lamps on the other side of the train.

Figure 5: Impression LED headlamps

Seven train drivers have taken part at the test. The average age of the drivers was about 50 years. Older people have on average less night vision and are more sensitive to glare (worst-case).
The headlamps where assessed from the drivers cab and from a platform. Every driver has made the same test drive; firstly with the LED lamps and secondly with the original lamps to judge the differences. The assessment as an observer of the train was made at the station of Schagen with a stationary train. Afterwards the drivers filled in a questionnaire and the experiment was discussed.

3.4 Results

Being seen
LED-headlamps are visible at great distances. Seeing the headlamps in the dark isn't critical. But visibility problems during a sunny summer day aren't to be expected because of the light intensity of about 2000 cd in the centre.
At about 800 metres the headlamps start "separating". The LED-headlamps are in this aspect comparable to passing trains with light bulb headlamps. The removal of the original spreading pane has a positive effect because the headlamps tend less to blend together.

Seeing
The aspect of seeing is very much improved. The high beam illuminates the track more but not too much in relation to the visibility of rail signals and the relative dark driving desk in the train cab. With high beam signs are at great distance (90 to 120 metres) visible and at short distance good readable. With low beam signs are acceptably readable. Switching from high to low beam doesn't create a sudden darkness in front of the train.

Avoiding glare
Train drivers judge LED high beam and low beam as somewhat bright but not too bright. The low beam has to be used to avoid glare of people on/near the track at short distance of the train (e.g. shunters, track workers).

Assessment LED headlamps by train drivers
On a 10-points scale (like report marks 1 to 10) the aspect of seeing a train on a great distance improved from 4,9 to 8,7. The visibility of signs, safety clothing and other objects on/near the track improved from 3,6 to 8,6. Avoiding glare slightly improved from 7,0 to 7,3. The overall score (on a scale of 1 to 10) of the original lamps is 4,5 and of the LED lamps 9,3. The original light bulbs are considered to be “reasonably weak”. Train drivers consider LED to be reasonably bright but still not too bright.

3.5 Conclusions and follow up
On basis of the assessment by train drivers it is concluded that the LED headlamps are a great improvement compared with the existing light bulb headlamps without additional disadvantages. The LED-headlamps meet the stand-still principle to safety.

Good visibility of signs depends also on condition of the signs (regular cleaning, use of (better) retro reflective material).
Some circumstances have not been tested (visibility at great distances on a sunny summer day, use during poor visibility situations like fog). In future practical tests these have to be included.

4 Benefits of Human Factors
It is obvious that, in both applications described, the business case of implementing LEDs is driven by technical/economical issues like improved reliability, longer lifetime, less replacements, lower energy costs. We have shown that one can easily get ‘blinded’ by these major economic benefits and may become unaware of introducing human factors risks. These risks will influence the business case sooner or later, however the extent depends on the effect of the eventual incident. Such incidents may differ from a driver missing a stop signal without further consequences to an accident with fatalities. On the other hand, a well made technical design will not only prevent risks but introduce efficiency satisfaction to its users.

The benefits can be divided into economical and non-economical (in EUR). Economical benefits are easily to state in EUR. Non-economical benefits can’t, or more difficult, be expressed in EUR.

The economical benefits of human factors consulting are:
- to the client: more efficient development period;
- quick acceptance by notified bodies and avoiding a second certification process;
- to the end-user (train driver): better performance and more safety.

The non-economical benefits of ergonomic consulting are:
- to the manufacturer: train driver involvement and approval as a unique selling point
- to the client of the client: more confidence in a good usable solution.

We will elaborate benefits, in which both economic and non-economical sometimes go hand in hand.

More efficient development period
More cost during headlamp development could be expected, based on the experience with the signal case where problems came up after the first development. This can be the extra costs of a series of tests as compared to one comprehensive test at the start.

Quick acceptation by notified body
Notified bodies will require re-assurement that the new light technique does not introduce new risks (stand still principle). A Human Factors based risk-analysis can provide arguments that can be helpful to limit the number of field tests. A field test can be costly, or even impossible, to conduct.

Safety and performance
Passing a red signal (SPAD) is a major risk. Causes of SPAD's can be:

1. Reading the wrong signal because it is too bright and conspicuous where it shouldn't be.
2. Blinding of train driver by head lamps, this can lead to misjudgement of a signal along the track.

Passing a red signal often causes damage of a switch. The repairing of a damaged switch costs about 30.000 EUR (direct cost, in year 2007). Less frequently trains collide after a SPAD, which is even more costly. If the ergonomic consulting can prevent only one SPAD with one damaged switch the invested "human factors" money is easily regained.
Trouble reading signals can also cause unnecessary braking of a train. This costs a lot of electrical energy, and will reduce the punctuality.

Approval of train drivers and avoiding signal re-placement
When a new LED signal is placed and complaints from drivers or even SPADs come up, there is a need to review its position or extra gear like for instance a hood. Replacement of a signal is estimated costing some tens of thousands of euros.
If serious complaints about LED signals would arise after placement throughout the country this would obviously lead to dissatisfied drivers and possibly a very costly redesign.

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