Real Driving Benefits and Research Findings with Digital Light Functions

M. Hamm, Audi AG, Germany

Keywords: digital light, glare, safety

1 Abstract

New human-machine interfaces are the direct result of digitalization. So also in lighting, new constellations have to be taken into account. High-resolution Digital Mirror based headlights make new lighting interaction feasible. Besides the quasi static low beam function, additional informations can be given to the driver. This will be possible because the pixelization of light allows symbols, patterns or just lines that are added or overlaid to the normal lighting pattern in a night drive situation.

Lighting via a dynamic street display is a new visible effect. Since projections on the road had not been anticipated by the makers of regulations, there is no mentioning and there are few investigations about positive or even negative effects available. But the safety contributions will be an important argument for the intended integration in the regulatory framework. A substantial concern for rulemaking is the question about added glare contribution. Distraction and glare is not intended and it must be quantified whether or not the digital light projections impact is significant. A real time driving study had been designed for the safety benefits and glare issues on dry and wet roads.

2 Safety Analysis for Construction Zone Light

Construction zones by night are areas of increased accident risk.

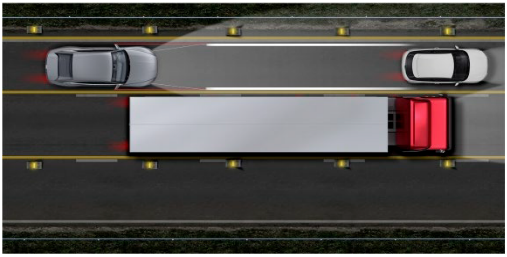

Figure 1:

Knowledge of the driver's vehicle width plays an important role in evaluating the passing risk [2]

The construction zone light as understood in this paper projects two light stripes on the road anticipating the width of the vehicle on the coming scenery in the area of roadwork. Basic intention is to increase safety and comfort for the driver. Since there are many possibilities of creating a stripe by gradient, length and shape, this investigation covers one of the simplest forms.

Critical situations during nighttime driving can be an overtaking or passing attempt on multi-lane road, where the outer lane is used for overtaking and on both sides are massive objects, like in Fig. 1 there are limits by a truck on the right and delineators at the left side. The overtaking situation has to be evaluated whether the width of the lane during the dynamic driving situation is sufficiently safe for the driver to overtake.

Construction zone with varying lane direction

Passing or overtaking other vehicles in construction zones may be additionally complicated when the lanes show curvatures. In many cases the curve radii of the lanes are rather small and require quick and precise steering reactions by the driver. In Fig.2 the lane change covers two lanes on a total of approx. 75m.

Figure 2:

Example of a situation where the lanes in a construction zone show some curvature and reduction in width [3]

The ultimate difficulties in construction zones occur, when the lanes are curved and additionally the width of the driver's lane changes. German motorway lanes are constructed with a standard width of 3,75m, giving for two lanes a total width of 7,5 m [4]. Fig. 2 already shows a decrease of the lane width from 3,75m to about 3m.

Test Setup for Construction Zone Light (CZL)

In the first scenario the test persons are driving in an artificial construction zone where the lane width changes significantly, as described in Fig. 3. The test persons were driving a car with a prototype headlamp allowing a Construction Zone Light projection.

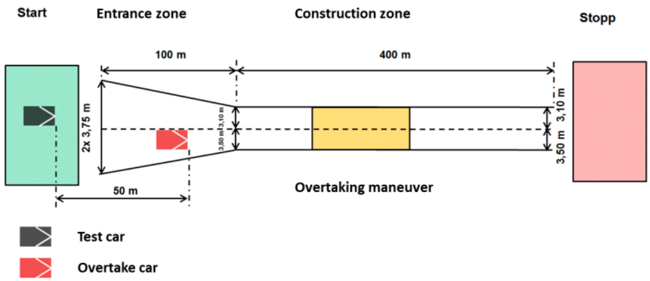

Figure 3:

Test setup for an overtaking maneuver in a construction zone.

Test persons had to start in the prototype car where the additional construction zone light could be activated by the test supervisor. In Fig. 3 the setup is shown in detail. The basic distance to the overtake-car was 50m. Both cars had to accelerate to normal driving speed. The test persons were instructed to overtake the second car but should only do so when they felt able to drive safe. The basic lane width of 3,75m was limited to a lane width for the test car of 3,1m. Compared to the actual allowed construction lane widths in German motorways [4] the test setup was not in the range of worst case but in a normal construction zone width.

21 Test persons performed the test during comparable night conditions, i.e. no rain, dry and normal wind conditions.

Physical Test Results

The test showed that many impact parameters have to be considered in order to achieve substantial results. Since not every driver was able to repeat his driving behavior when driving multiple times an identical test scenery, some of the results were not delivering consistent results. Recorded parameters like deceleration or acceleration profiles did not deliver reliable results in this test.

Steering Wheel Movement

When the analysis was limited to the steering wheel movement during the test scenery, especially when looking to small angle variations when the drivers where entering a construction zone with limited lane width, some interesting results could be derived.

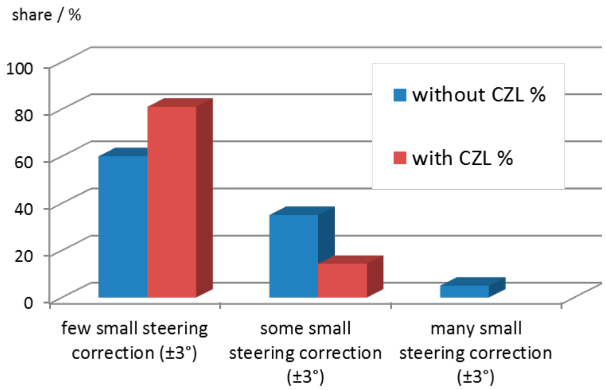

Figure 4:

Analysis of small steering wheel corrections when test drivers were passing and overtaking a car in the test setup described in Fig. 3.

The analysis of the recording of steering wheel corrections showed different behavior of drivers with or without CZL. About 80% of the drivers used less than 3 small steering corrections. On the other hand, the standard overtaking situation without CZL showed only about 60% of driving situations with less than 3 (=”few”) , and about 35% between 3 and 6 (=”some”). Only some drivers without CZL needed more than 6 steering wheel corrections (=”many”). The analysis summarized in Fig.4 indicates that a driver with an activated CZL needs less corrections. Fewer corrections indicate the drivers were better enabled to guide their car safely through the difficult situation in the setup.

Gas Pedal Position During Takeover

Any speed change in a critical situation (without escape chance like in a construction zone) can lead to car to car accidents and enormous traffic jams creating additional danger. So it can be assumed that a system that can enable the driver to drive through such critical situation without dramatic speed change will improve traffic safety.

During the test setup the overtaking situation also the gas pedal position was recorded.

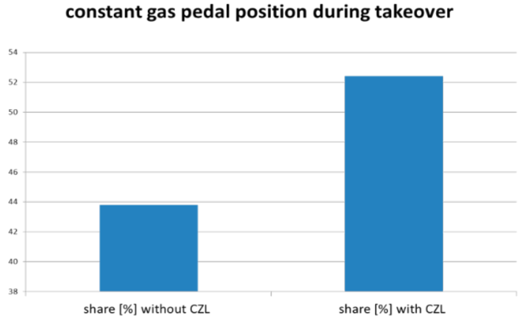

Figure 5:

Analysis of gas pedal position of test drivers in the setup described in Fig. 3.

In Fig. 5 the share of test drives are displayed where the test drivers did not change the gas pedal position during the test setup takeover activity. Change of gas pedal means changing speed and a potential accident root cause. In about 15% more driving actions the test drivers with CZL did keep the gas pedal position constant. That indicates, the drivers were able from the very beginning of the overtaking situation to correctly evaluate the situation and felt no need to brake or accelerate their activity. This corresponds quite well to other studies investigating digital light benefits [6].

3 Glare Research

Parameter definition

Focus of the investigation was a passing car situation at night with wet or dry road conditions. A test track was found in the Audi driver experience center in Neuburg Germany.

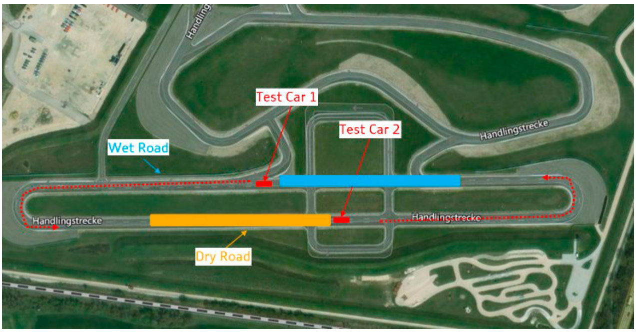

Figure 6:

Test track used in the study for wet and dry road condition

Two interconnected about 500 m long and three lanes wide roads could be used (Fig. 6). In order to compare both situations with the same test person collective, two different road conditions wet/dry were created. To create a wet surface, several proposals had been investigated. Artificial solutions e.g. with plastic foils were rejected because of the need of a large covered area of more than 50 m in length and more than 7 m in width. Most probably a driving over a foil would create disturbances and fluttering foils by the car generated air movements.

Figure 7:

Water irrigation system used to guarantee a wet surface in night drive 2.

A sufficiently efficient solution was given by a mobile irrigation system normally used for professional driver's skill training in skidding and slipping. Before and during the tests the system guaranteed the permanent moisture of the selected test areas. Each irrigation used about 500 liters of water. The water spray started before the test and was repeated about every 15 minutes, Fig. 7. With the help of the water irrigation system, the night drive situation could be very perfect and effective adjusted to real wet situations.

Figure 8:

Road condition for wet road glare rating test in night drive 2.

A driving scene with a wet segment is shown in Fig. 8. In the picture the test car on the right lane is projecting the light distribution and an oncoming car is approaching on left lane.

Glare ratings had been recorded in two night sessions. In one session (night drive 1), there was no need for additional irrigation. The road was due to heavy rain sufficiently wet.

Glare Measurement and Situations

The investigation concentrated on glare created by three different light patterns: a) Low Beam, b) Low Beam with Digital Light Projection, c) High Beam.

Of high importance was the definition and evaluation of the relevant glare situation. In order to create comparable results with several test persons, a setup using visual tasks was chosen. While approaching the test car with the relevant light distribution, the test persons were asked to fixate a computer screen that was installed at the right side of the driving path. This computer screen displayed a random two letter combination. At a distance of 50m ahead of the test car, the drivers were asked to fixate the monitor, read the letters and in parallel to rate the glare level of the test cars light distribution.

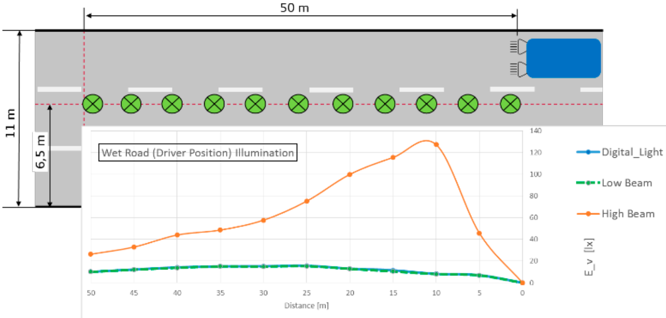

Figure 9:

Illumination measurement during wet road condition. The measurement was taken at 6.5m from the right edge of the street.

The differences for dry and wet conditions have also been expected, since the amount of direct reflected light is dominating the photometrical measurements. A factor of 5 to 6 can be estimated as additional contribution via the wet street reflection.

As a summary of the photometrical investigations, the glare evaluation of low beam and digital light is expected to be quite similar, whereas the high beam glare evaluations should show much bigger differences.

Test persons and Methods

A total of 44 test persons participated in the night drive tests which were conducted during two nights. All test persons were tested on normal visual acuity and color deficiencies. Test persons were instructed to drive with constant speed and rating of driver and passenger was recorded individually. Before the recorded test drives, a learning round was performed in order to make the test persons used to rating and the test procedure. Discomfort glare in lighting has been evaluated in many ways since the early 40s by psychophysical evaluations. In the presented study a 9-scale subjective glare rating following the de Boer rating and wording was used [7]. For all driving situations about 300 different ratings could be analyzed.

Glare Rating

The test persons were asked to drive with a continuous speed of about 40km/h which is equivalent to 11.11 m/s. Since the test was a dynamic test, it must be taken into account that between passing the 50m mark and the final rating approx. 1..2 seconds passed by. So the evaluation of glare seemed to be not only a static snapshot rating at a distance of 50m, but could also cover the dynamically changing glare conditions between 25..50 m.

The overall rating results from the two experiment nights (Fig. 10) show very consistent results with the photometrical measurements (Fig. 9). Subjective glare in high beam was rated significantly higher than the both other functions.

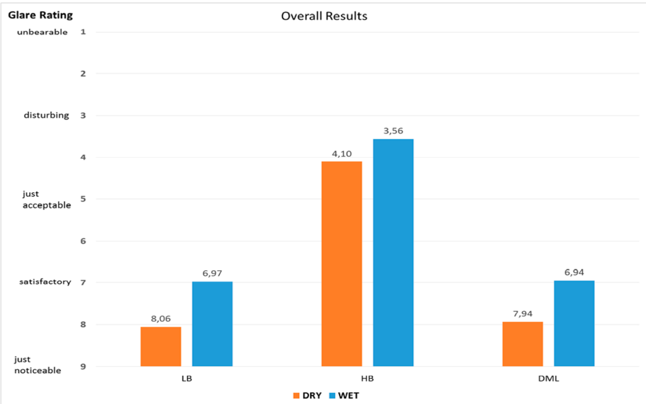

Figure 10:

Overall glare rating results for all night driving situations.

Each inner comparison of the ratings between dry and wet road conditions shows clear differences. Wet roads were in any condition rated higher. For low beam and digital light the difference between wet and dry road conditions was a full digit from a rating about 8 to a rating about 7. The rating 7 means satisfactory in the glare rating setup.

The high beam was anyhow rated much worse, the rating increased from 4.1 to 3.56 which was in the wording area of “disturbing”. Looking to the differences between low beam and digital light (i.e. low beam plus digital road projection) there was a very small delta of 0.03 rating points respectively 0.12 rating points. Both functions were always rated in the verbal range of “acceptable”.

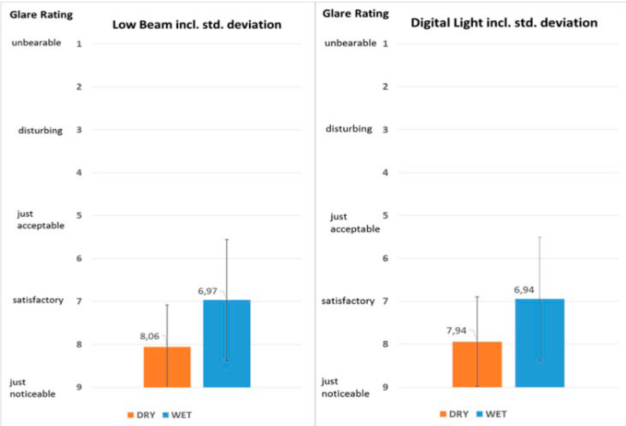

Figure 11:

Comparison of overall low beam ratings and overall digital light ratings.

An analysis of the standard deviations derived from the dry and wet ratings for low beam and high beam did also show no difference (Fig. 11). Standard deviations for dry road conditions resulted in 0.98 and 1.04 rating steps, whereas in wet conditions the standard deviations increased to 1.41 resp. 1.43.

The conclusion of the overall results is that like from the photometric measurements expected, no additional glare or increased subjective rating is found comparing a low beam and a digital light.

4 Summary

Digital lighting functions are supporting the driver’s comfort and safety. Especially with construction zone lighting (CZL) the effects are visible with recordable physical parameters. The steering wheel corrections are reduced and the gas throttle position is kept about 15% more unchanged in a construction zone. That gives evidence that digital light is improving safety in such critical situations.

In all road conditions and glare angle variations, the high beam situation increased the rating results about 3.5..4 rating points. This is the only and a significant change in all ratings. Every reader might have experienced that low beam glare at night might be not pleasing, but high beam glare can be really disturbing.

Glare exists on wet roads, adding a large dynamic amount of reflected light into the driver's eye. All experiments and measurements showed that the digital light projections do not create additional subjective glare compared to a standard low beam light distribution. There have been concerns about such negative effects. This study completely refutes such concerns.

The results that digital light does not create additional glare was approved valid for dry roads, wet and very wet road conditions.

As shown, there are many positive safety effects from digital light. The results demonstrate that digital light has no negative traffic safety impact.

5 References

[1] Hamm, M., Huhn, W. Reschke, J.: Ideas for Next Lighting Generations in Digitalization and Autonomous Driving. SAE Paper 2018-01-0516.

[2] Omerbegovic, S.; Funk, C.; Reim, J.: Construction zone light: A study on safety and distraction. In: ISAL; Vol 17. München: Utz, 2017. pp 307-314.

[3] https://www.fnp.de/hessen/angst-baustelle-10528199.html.

[4] Forschungsgesellschaft für Strassen- und Verkehrswesen: Richtlinien für die Anlage von Autobahnen. RAA. Köln: FGSV-Verlag, 2008.

[5] Hamm, M., Huhn, W.: Glare Investigations and Safety Research on Digital Light Technologies. SAE Paper 2019-01-0849.

[6] Budanow, M. et.al.: Information System for Car Drivers Based on Projections on the Road. In: Proceedings IFAL 2018. Shanghai: Fudan University, 2018.

[7] De Boer, J.; Schreuder, D.: Glare as criterion for quality in street lighting. In: Transactions Illuminating Engineering Society. Vol.32. pp. 117-135.