

ISAL 2019 CONGRESS Report

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ISAL 2019 Steering Committee

Since 1995, the International Symposium on Automotive Lighting, organised every two years by the Technical University of Darmstadt, has become a primary globally recognised forum for vehicle lighting technology. This year there were close to 900 attendees from Europe, Asia, and North America. Notably, this year's proceedings contained only a few minimal, passing mentions of halogen technology. Two of the main focal points of the congress this year were communication between automated vehicles and other road users, and high-resolution headlighting systems. These topics are timely, of course, and they've also rapidly moved out of the theoretical and into the practical realm; in fact 15 million ADB-equipped cars of about 60 models from numerous makers are on the world's roads—except in the USA—without any reported problems.

EXECUTIVE SUMMARY: Takeaways

Here are ten key points we retain from the two days of lectures, panel discussions, keynote speeches, and poster presentations:

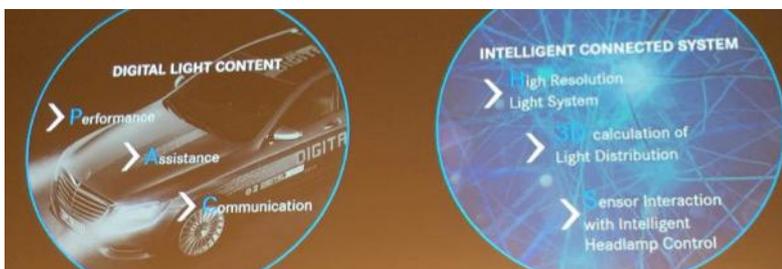
- Technical constraints that confined to high/low beam systems have been removed by ADB, which is expanding into high-volume, popular-price models. The high/low-beam binary which has never been good enough for the job is obsolete; how long it takes to die out remains to be seen.
 - Recent ISALs had a strong focus on ADB, mostly looking at systems and ideas for 8, 16, and 32 segments. This year was different: still a predominant focus on ADB, but on high-resolution systems, no longer with a few segments.
 - Road image projections for new kinds of turn signal and reversing lamp repeaters, vehicle-width guidance through lanes narrowed by construction, and other such driver-aid functions are under very active development.
 - Visual communication using front and rear lights to help pedestrians and other drivers is another area of strong developmental interest.
 - Displays for V2X communication and brand communication are arriving.
 - Monolithic SSL, μ LED will be more and more used to make ADB, road projections and visual communications.
 - Regulations must be modernised to be technology-neutral for robust resistance to obsolescence and must be harmonised for worldwide standardisation. Testing methods, too, must keep up with new technology so as to assure the measurements are in accord with the actual, effective performance.
 - Laser and OLED are rapidly being developed and commercialised in ways that overcome technical and technological challenges reported as recently as last year.
 - Integration of sensors as camera and lidar will be used in the future.
- The convergence of ADAS, AD, and lighting systems carries on at an accelerating pace.
- Software will become more and more important in lighting with a change of value chain.

Session: High Resolution Headlamps and Digital Light

Necessity to Work on Use Cases Before Implementation of Digital Light Systems

Introductory speech by S. Töpfer (Daimler)

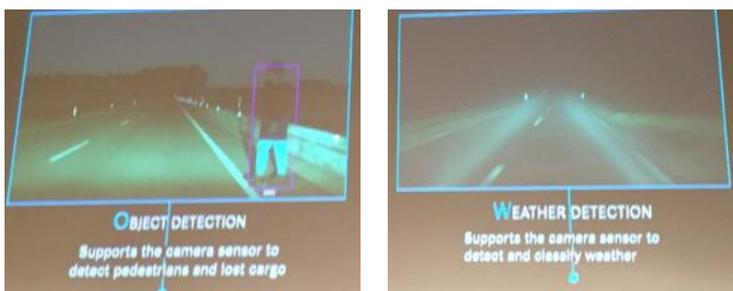
S.Töpfer introduced the session, showing that the movement towards digitalisation of headlamps started with the Multibeam LED first installed on the CLS-Class in 2014 with 16 pixels, followed by the E-Class with 84 pixels in 2016, and the S-Class Maybach in 2018 with 1.3 megapixels. There are key enablers for digital light in Hardware with DMD, μ pixel-LED, μ AFS, and MEMS, and in software with sensors, signal fusion, and 3D calculation in the vehicle backend and user interface.



Benefits for digital light are the best illumination, provisions for light-based assistance functions, and communication and interaction with other traffic participants. The first step is to define use cases and vehicle integration.

The target is naturally to reach or exceed today's performance with the best systems using AFS and ADB, and to evaluate the added value for assistance and safety: it is necessary to focus on safety-increasing use cases and scientific evidence of safety benefit.

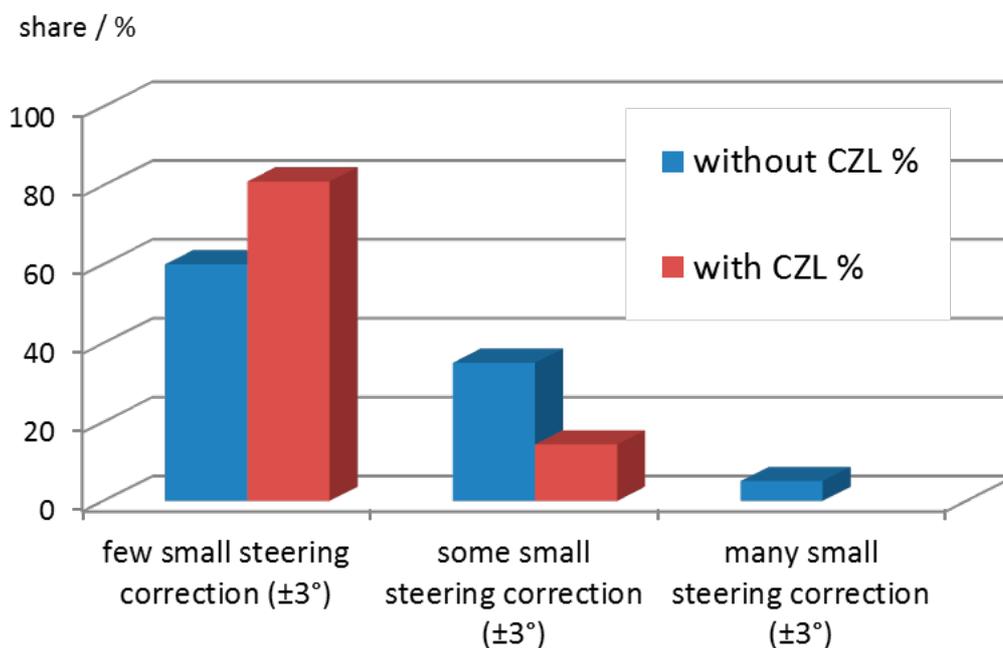
After a clear view of the different use cases, the design of digital light can be done with optimised light sources and modules, with a clear target for every specification: luminous flux, illuminance, field of view, etc. There are many challenges for digital light to succeed; along with the technical challenges, it will be necessary to define a regulatory framework based on reasonable rules and restrictions and enabling worldwide deployment.



Object detection (L), weather detection (R)

We are still at the beginning of the story. Future trends in digital light could include extension to a 360° installation including high resolution light distribution for front and rear lights and near-field projection all around the vehicle; and the use of digital displays to indicate vehicles status (autonomy levels, state of charge, etc), and the integration of display functionalities in lighting units and/or the car body.

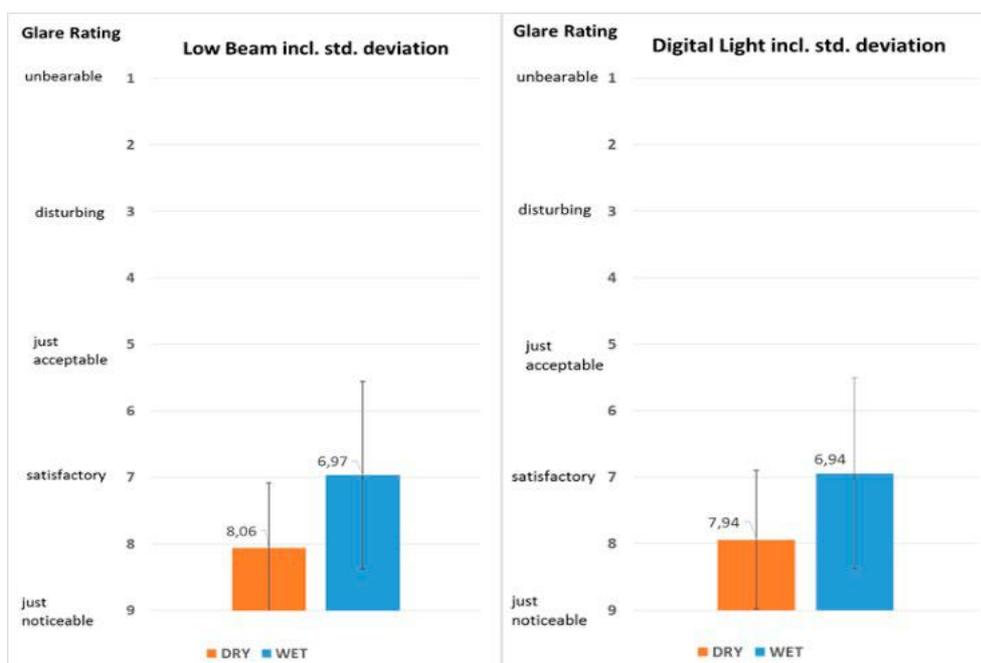
Audi's Michael Hamm investigated the effect of new digital functions to road safety, distraction, and glare. He found no additional glare, and strong indications that digital light is improving traffic safety.



In a test setup, a construction zone with lanes narrowed from 3.75 to 3.10 metres was built. The goal was investigation of a construction zone light with stripes that indicate the width of the car, projected forward to help guide the driver through the zone. The outboard verge of the lane was limited with delineators, and a car on the second lane should be overtaken. The speed was 80 km/h for the test car and 60 km/h

for the other car. The outcome showed that overtaking drivers with construction zone light were much steadier on the steering wheel and other car controls (accelerator position was kept 15% more constant, for example) than without the construction zone light. 95% of the drivers gave a "very good" or "good" rating to the construction zone light. This indicates that in difficult situations the car-width guidance projections give better estimation capability for the driver. The test drivers could pass the construction zone more safely without generating dangerous situations.

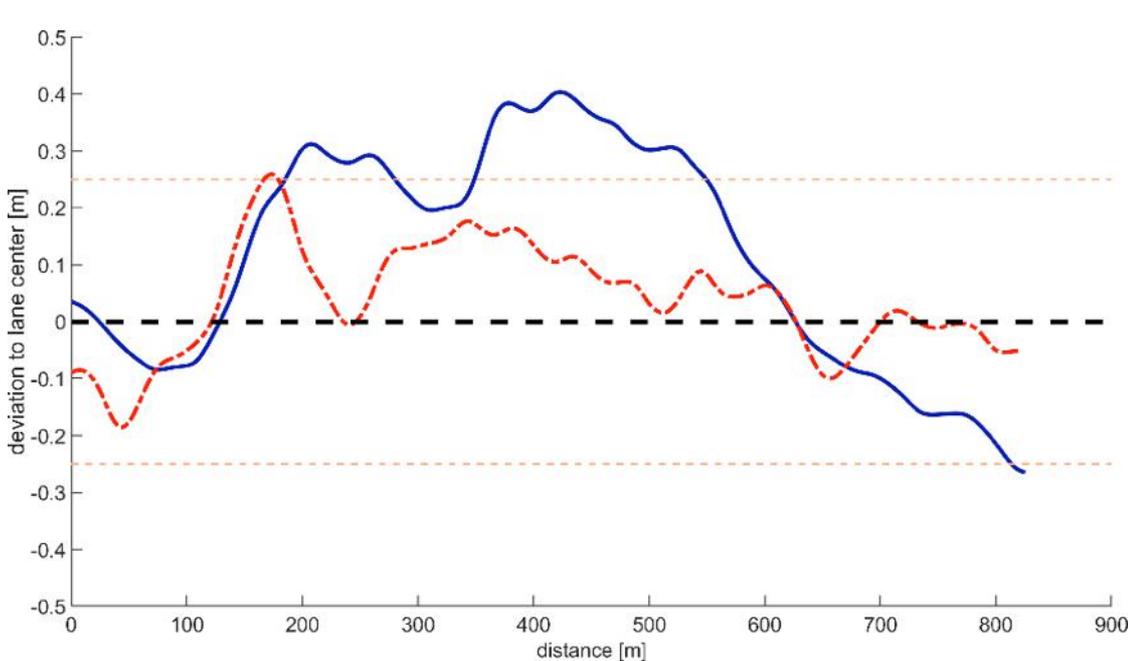
In a second experiment, it was investigated whether there is additional glare from digital projections. This was investigated in dry, wet and very wet road conditions. Test drivers had to assess the glare of different lighting situations. The glare rating was performed on a 2- and 3-lane road to check different glare angles. 44 test persons participated. The results in photometry and de Boer ratings showed that there was no significant increase in the glare ratings at all from digital projections.



Dr. Rosenhahn demonstrated that the driving behaviour is significantly influenced by road projections, the car is much better centred and traffic safety is improved by the road projections.

High Resolution Systems in headlamps provide highest flexibility during all adaptive driving situations in nighttime. High flexibility in cutoff line management (low beam & ADB) generate significant advantages in range and visibility for the driver. In addition to these advantages the opportunity of assistance projections on the road for driver information or driver assistance are realised by high resolution headlamps.

With a test car equipped with a DMD projection system integrated in a prototype headlamp an investigation of driver assistant guidelines as a road projection in a real driving situation was carried out with test subjects. The target was to investigate if the guideline elements, which are projected to the road in front of the car, have an



influence on the driving behaviour.

For the analysis of the driving behaviour the lateral position of the car on the own lane was measured by the on board camera and analyzed after each test run with and without road projection guiding elements. For characterisation

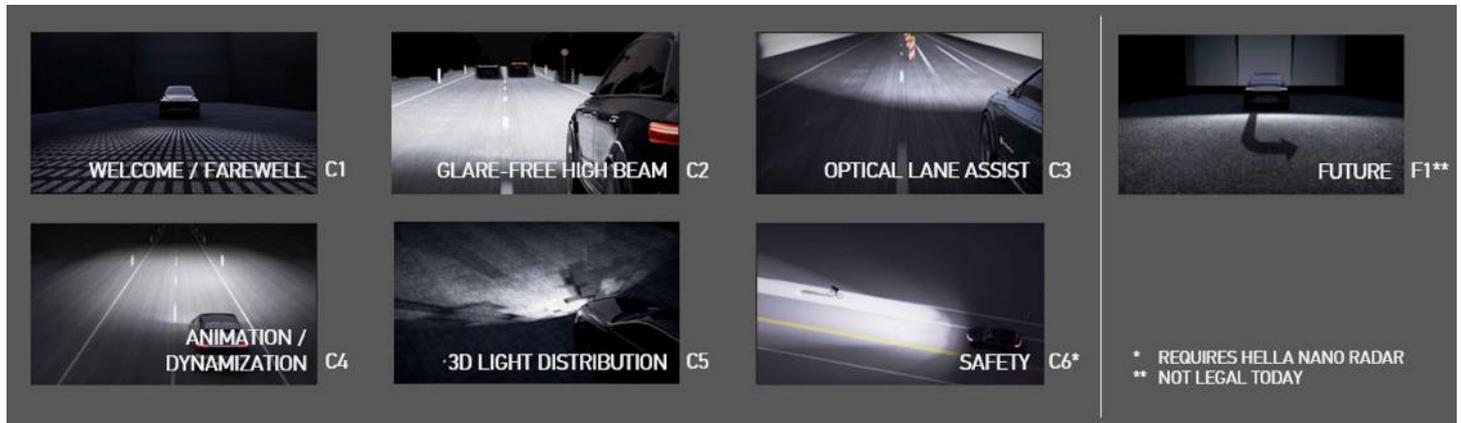
of the driving behaviour, a safe driving corridor was defined. The test subjects drove along a construction zone with lanes about 2.40 m wide. The car width was 1.90 m between the tires. The safe driving corridor was therefore defined as car width + 25 cm on each side. The plot presented here shows much less deviation from the centre of the lane with the guide lines (red dashed line) than without them (solid blue line).

The safe-driving corridor was violated (departed from) for 25% of the time without road projection guidelines. With guideline projections, the out-of-bounds time is reduced on average to about 5%. This clearly demonstrates that driving behaviour is definitely influenced by road-surface vehicle width projections, as the car is much better centred and traffic safety is improved by the road projections.

Boost Safety & Styling—New HD-LED Systems for Front and Rear

Dr. M. Kleinkes (Hella)

Veteran Hella scientist Michael Kleinkes explained in this lecture how high-definition SSL lighting and LED displays will offer new means for digital front and rear lighting with benefits in safety, styling, flexibility (e.g., animation), and communication with the vehicle owner and other traffic participants. HD-SSL light sources are based on a super-integration of a single silicon ASIC (application-specific integrated circuit) supplying several thousand LED



pixels individually. They are supposed to become the light sources for future HD headlamp modules.

Improvements in the form of smaller pixel sizes, larger light emitting surfaces, higher pixel counts, greater luminance and contrast between the pixels, and better homogeneity of the luminance will allow new use cases with high light quality and performance.

The use cases of HD-SSL can be grouped as those supporting safety and those which have a major styling impact. Automotive exterior displays are the next evolutionary step for sophisticated signal functions. They will be placed wherever they are useful. The display technologies currently under discussion for automotive applications are LCD, AMOLED, LED matrix systems, and μ LEDs with size < 0.3 mm.

Personalised welcome animation or advertising video signal lighting functions are on the way to transform into new styling possibilities and safety features. In the near future, car makers will offer digital products to their customers like personal animations and videos showed anywhere on the car body.



Micro-Pixel LED Headlights Dr. J. Roth (Volkswagen)

Dr Roth presented the variety of technologies for HD lighting, and explained the advantages of micro-pixel LED with their acceptable power consumption independent of the light distribution, the variety of suppliers, and their relative affordability.

Based on crash analysis, micro-pixel LED headlamps could bring improved safety by reducing rear-end collisions,



lane departures, pedestrian hits, and collisions at road junctions (intersections).

For each accident-prone condition, a specific light can reduce the risk. Examples include guide lines for lane departure (upper left), a triangle go warn drivers

drifting out of lane (lower left), a line showing perpendicular traffic a car is approaching their path (upper right), and pedestrian highlighting (lower right). But before implementation, Volkswagen are doing preliminary research, including the development of the functional mockup presented here.

The design concept of the demonstrator targeted an increased illuminance by superimposing the output of several modules with the assumptions of a luminous flux of 4096 lm per module and an optical efficiency of 0.4. Each headlight has 30 individually-addressable megapixels covering a field of 30° H × 10° V. The prototype was installed in a VW Polo. The target was to achieve an illuminance of 120 lx. The illuminance decreases with the horizontal field of view. Several modules must therefore be used, superimposing some areas to achieve the illuminance target and different concepts for this superposition were analysed.



A micro-pixel headlamp prototype was realised based on these concepts, reaching 4,423 lm and 116 lx. It uses specially developed electronics from Infineon, and Osram's Eviyos light source. The target of Volkswagen is to use this technology not only on high-range cars, but also on small cars in accord with their

democratisation policy.

Adverse Weather Light—New Approaches to Evaluate Adaptive Light Functions A. Thoma (L-Lab), M. Vollrath (TU-Braunschweig)

This lecture reported on experimental efforts to address one of the use cases not adequately catered for by current-production adaptive headlamps, which do a fine job in good weather. But inclement weather conditions such as fog or snowfall cut seeing distance, depriving the driver (human or machine) of crucial information needed to make the right driving decisions. The goal is to leverage the potential of high-resolution headlamp systems to provide optimal visibility in bad weather. The basic intent in foggy conditions, for example, is to achieve high object contrast while minimising backscatter and its resultant self-dazzle.



The authors go into the defining aspects of roadway illumination for various atmospheric conditions. In light fog when the low beam range is inadequate, the cutoff could be raised to provide greater distance reach without the above-horizontal high beam light that would cause backdazzle. In heavy fog, the cutoff could be lowered. That amounts to lowering the amount of light above the cutoff; another strategy is to increase the amount of light below the cutoff. Another approach would be to have the nearside headlamp produce more light and the offside lamp produce less, with the overall output the same. This would reduce scattered light in the driver's direct sight lines. Also, foreground light can be reduced, and different kinds of asymmetry can be realised: strong lateral light, for example, with reduced straight-ahead light. This is all easier to achieve now than ever before, with high-resolution headlighting systems.

With so many different strategies, which ones work best? That answer was not the goal of this work. Rather, the experimenters meant to find a reliable, practicable way to evaluate adverse-weather lighting. They put together three studies, one with artificial fog and two with natural fog, focusing on the driver's subjective feeling of safety and on objective, measured real seeing distances. Participants drove a test car with high-resolution lighting in fog. Two different light distributions were presented, and participants had to pick a favourite. The authors note the great difficulties in getting reliable, comparable results in an inherently unstable and unpredictable condition such as fog, and recommend conducting studies in artificial fog as it is most conducive to obtaining objective measurements and reproducibility.

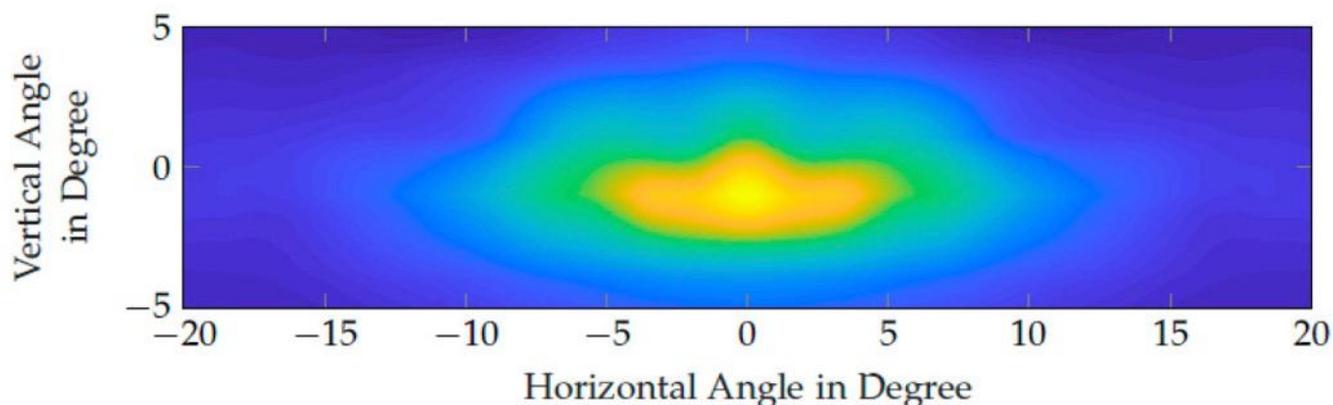
Object and Gaze Distribution Based Optimization of Low and High Beam

J. Kobbert, K. Kosmas, T.Q. Khanh (T-U Darmstadt)

The researchers here noted that although a great many adaptive headlighting systems are now on the roads, with more being commercialised all the time, the basic light functions and beam distributions have not changed. In response to this, they propose a new method of optimising light distribution based on traffic and driver-gaze behaviour. Their research involved 54 test subjects and a total of more than 6,000 km of night driving on city and country roads and motorways. Gaze direction, illuminance at the driver's eye, and the distribution of other road users and traffic signs were recorded. All the resultant data was integrated to arrive at a new light distribution.

A tensor flow network was used on the data. To train it, 500 captured frames were manually marked, then used to train and test the network. 70% of the marked data was used to train the set; the remaining data was used to test the network. Accuracy generally ranged from 25 to 65 percent, with the low end of that range applying to traffic signs and the high end to other cars on the road. Eye tracking data was treated differently and greater accuracy rates were attained. Some interesting findings accrued from the eye tracking data: it provided results in accord with most all previous such data, contradicting only one previous finding.

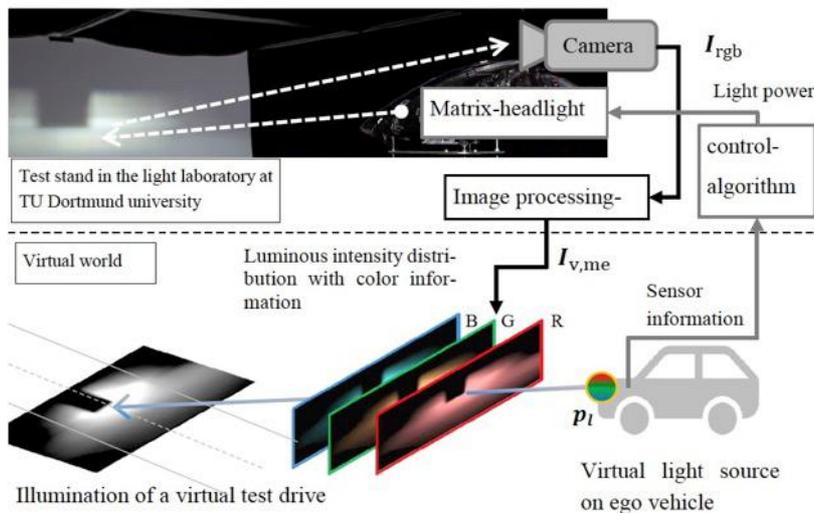
Perhaps one of the most interesting outcomes of the research is the result of combining and processing the collected data in appropriate ways defined by the researchers. The result is what the researchers call an optimised light distribution based on contrast measurements for detection, object distributions, and gaze directions. That light distribution, which is produced here, bears a striking resemblance in overall shape to a traditional US (SAE) headlight beam pattern:



The researchers point out that while the optimised and conventional beam patterns have about the same intensity at H-H, the optimised beam pattern is significantly more intense at 0.5°D, and the optimised beam pattern contains substantially (50%) more light flux.

Evaluation of the Light Distribution of a Matrix Headlight With Hardware-in-the-Loop Simulation (M. Waldner, T. Bertram (TU-Dortmund))

This paper presents a new method for evaluating high-resolution headlighting systems using hardware-in-the-loop (HiL) techniques, in response to the increasingly steep challenge of modelling and virtually developing and testing headlamps as they grow more sophisticated and higher in resolution and capabilities. The described system digitises the light distribution of headlights in real time, and then applies it to illuminate virtual testing scenarios. The digitised light distribution matches the actual light distribution in intensity and colour, making this approach applicable to headlamps with varying levels of resolution and different technologies. The authors point out that the HiL method is key to reliably being able to virtually evaluate a headlamp system in real time at any daytime under reproducible conditions".



The first step is digitising the light distribution by means of a camera system. An algorithm evaluates the captured images and calculates the luminous intensities. The resultant virtual beam is used to illuminate a virtual test environment. Then the real headlamp's light distribution is adapted to the virtual scenario—that's the closed test loop, and it allows iterative testing of the headlamp in scenarios that can be difficult to attain once (let alone multiple times) in the physical

world. The use of the real headlamp as the light source minimises assumptions and simplifications, thus improving the fidelity and resultant dependability of the simulated tests. The resolution of the imaging camera is the limiting factor.

The paper goes into close mathematical and technical detail on the steps and processes involved in the visualisation, imaging, calculation, and simulation method, noting that it is iterated for red, green, and blue channels. The overall accuracy of the real-time visualisation is $\pm 20\%$ on high beam full scale. Blue edges of the light distribution caused by chromatic aberration and the inhomogeneities caused by the pixel overlap are visible in the camera data, and these kinds of brightness and color gradients within the light distribution are reproduced realistically in real time in the simulation.

Applications for the method include virtual test drives, headlamp system development, and detailed analysis of nonstandard operational modes—failure simulation, for example, or the effect of different kinds and degrees of lens occlusion by different kinds of dirt, or failure of any number of light sources within the lamp. The influence of any such thing on the headlight performance is readily visible in the virtual environment. Another application: stress-testing the headlamp in different environmental conditions. The technology also applies to very-high-resolution forward lighting systems; it can be used with a 2-megapixel beamer to simulate the road projection abilities of a DMD headlight system, for example. Here again, the camera is the limiting factor in the fidelity of the virtual light performance. The authors state that multi-camera variants of their system are under development, so as to increase the system resolution and allow for slow-motion videos to detect flicker from the system under test.

This lecture describes the roles headlighting systems must fill for successful automated driving, with emphasis on how Daimler's "Digital Light" system works toward safe nighttime automated driving. Basically: the visual task of "seeing the road" has always involved much more, for human drivers, than just perceiving the road itself (the strip of pavement). Like layers of an onion, the task is revealed to be complex: the driver must see the road, the markings on the road, the signs governing usage of the road, the pedestrians and bicyclists and other motorists using and approaching the road, obstacles in, potentially in, and near the road; the ambient conditions (light levels, weather) that will affect the safe use of the road (such as fog, shown in photo), and so on and on. All of this applies equally to machine drivers: the headlights must support the visual sensor chip of a camera to do all these



same tasks, and possibly more.

The authors point out that the human driver's senses are effectively replicated by all sorts of sensors, algorithms, and technologies to make decisions. The visual sensors, they say, analogous to human eyes, are crucial because they have the greatest spatial resolution and can provide a vast amount of

information like the shape, size, and colour of objects, they can read traffic signs, etc. They note that Tesla have claimed a purely visual sensor system will get the job done, while Ford have claimed the opposite: lidar and radar suffice without cameras or headlights. The Daimler team assert that in truth, adequate reliability demands a system with radar, lidar, *and* visual cameras, and that perhaps the most important role of the visual camera/headlight system is to support the sensor network of an AV by detecting objects, colours, and weather conditions at night. Examples are given where inadequate AV vision caused or contributed to crashes.

At night, AVs must be able to detect rain, fog, snow, and rain-slick or frozen roads. This can be done perhaps adequately by ambient light during the day, but at night headlamps are surely necessary. The authors note the paucity of research into the specifics of this area, and give an example of how an advanced lighting system can directly meet the needs: the Daimler Digital Light system, they say, can support the detection of bad weather by illuminating a specific region of interest, then measuring the intensity of the reflected light—thus providing a measure of fog density. Rain and snow detection can be added by assessing the degree of busyness, flow granularity, and regularity; meanwhile, the road surface conditions can be kept track of by reference to the headlight reflectance on the street.

Finally, the authors predict that evolution will bring closed-loop operation with cameras and headlamp systems controlling one another to optimise illumination *and* machine sensing.

Session: General Headlamp Topics

Introductory Talk: Kamislav Fadel (Senior Exterior Automotive Lighting Advisor)

	END CUSTOMER	OEM	TIER1	TIER2 <i>(Technology oriented)</i>
CONTEXT	<ul style="list-style-type: none"> • Not enough lighting sensitive • Options trade-of dilemma • Financial Crises • Youth is less car centric • Mega cities 	<ul style="list-style-type: none"> • Heavy Investments in EV&AV • CO2 reduction pressure • Shrinking Market • Increasing car segmentation • Increasing Lighting options 	<ul style="list-style-type: none"> • High speed innovation • Legislation evolution • Shrinking volumes per Ref. • Cost pressure • Fuzzy OEM mid term strategy 	<ul style="list-style-type: none"> • Shrinking market • Fuzzy Technology and product RM • Heavy investment in technology • Cost pressure
CONSEQUENCES	<ul style="list-style-type: none"> • Buy less cars 	<ul style="list-style-type: none"> • Cost cuttings • Arbitrations lighting unfavourable • Uncertain product roadmap • Uncertain technology roadmap • Reducing segmentations & Light options 	<ul style="list-style-type: none"> • Increasing financial risks • Increasing part complexity • Cost cutting • Reorganisation for more efficiency • Pivotal product and technology roadmaps 	<ul style="list-style-type: none"> • Financial risks • Technology roadmaps are pivotal • Risk to miss opportunities • Not cost optimized

Kamislav Fadel's speech developed three key themes:

- More collaboration and partnership in the value chain will optimise costs and reduce risks
- Innovations will fail unless they bring a clear added value
- More advertising about excellent lighting will enhance its prestige in end users' perception

How Vehicles Learn to Display Symbols

J. Reschke (Audi)

Communicating with other road users, especially with pedestrians is crucial for today's traffic. Signals for automated vehicles are not intuitively understood and therefore, need to be learned.



This contribution describes an algorithm to detect a driver's stopping intention, which can be used to display symbols to pedestrians.

The introduced algorithm consists of three stages. Stage one is forecasting. Stage two predicts the driver's willingness to stop with a true positive rate of 95.3% and a false positive rate of 4.5 %.

Combing all 3 stages, a true positive rate of 95.6% and a false positive rate of 2.1% is reached for a prediction whether the driver will stop within two seconds.

Every vehicle, whether operated by a human or by a robot, requires visual guidance systems in the form of lighting or other optical radiation that will help the operator avoid hazards and maintain appropriate position along the road.

For example, driver-pedestrian interactions at a crosswalk often involve such personal non-verbal communication

Type of communication	Number of articles
Lights/Lighting	18
Human-like features	4
Text/symbol display	17
Projection on the road	14
Sound	7
Cellphone messaging	4

such as eye contact, facial expressions, and hand gestures. These are not readily available to most, if any, autonomous vehicles. As a consequence, pedestrians may have a lower level of confidence or comfort when interacting with autonomous vehicles.

Noted vehicle lighting safety

researcher John Bullough tabulated recent news media stories about autonomous vehicles, notably about their V2X communications systems. The tabulation is analysed to help vehicle lighting decision-makers plan for responsible exterior lighting on driverless vehicles.

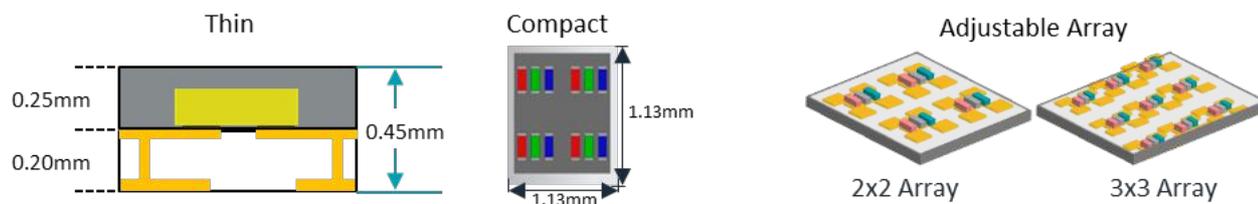
There is an infinite variety in the forms of visual communication that AVs can provide to road users, and this variety may persist as long as enforceable standards don't yet exist. In addition, even if there are minimum standards about signaling that AVs will be required to meet, auxiliary lighting and displays may still be widely used. These may have substantial benefits, as people clearly like and understand two-dimensional visual information (e.g., a spatial or symbolic display) better than one-dimensional information such as a signal light. At the same time, it remains important that AVs, like all other vehicles, utilise conventional lighting and signals (DRL, turn and brake signals) appropriately and consistently.

Study on Requirements of Exterior Display for V2X Communication According to Realising Functions
G.-D. Kim, N. Kwak, D.-H. Kim (Samsung Electronics)

As the autonomous driving era approaches, the authors point out, it is necessary for a vehicle to communicate with surroundings. Various studies are ongoing about communication methods and related subjects, including displays that can express information directly. This kind of exterior display has different requirements compared with already-common interior displays. While interior displays are viewed at close range, the viewing distance for an exterior display can be up to tens of metres, so high luminance and contrast are more important than high resolution.



After reviewing performance requirements for exterior displays, the authors described their study on the subject. The results: distance between pixels should be less than 1.75 mm in order to effectively deliver information at a distance of about 6 m, for the messages to be clearly legible in bright daylight the luminance should be higher than 12,800 cd/m², and the viewing angular range needs to be $\pm 80^\circ$ so observers at various locations can recognise the display and attain its message.

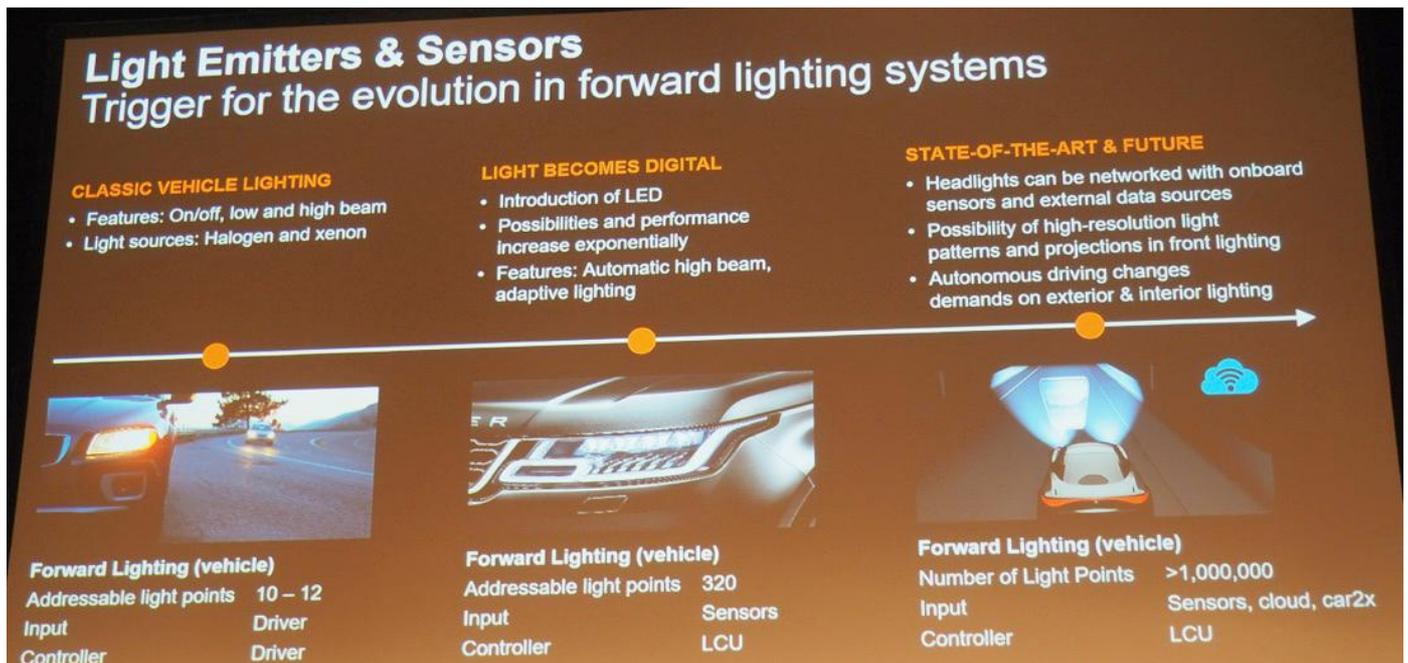


The authors described how and why Samsung's mini-LED products are well suited for exterior displays. Additional review of the requirements in terms of observation distance and the surrounding environment will be necessary. There are various solutions coming out for communication in the autonomous driving age, but it is important to figure out how best to show information in the end. Higher resolution and higher luminance may be required to convince buyers of the value proposition. In order to do this, we must share ideas and cooperate together to find meaningful functions and establish standards. Light source makers should continue to work on increasing brightness, set makers should consider how to configure their devices, and car makers should constantly consider what to show to customers.

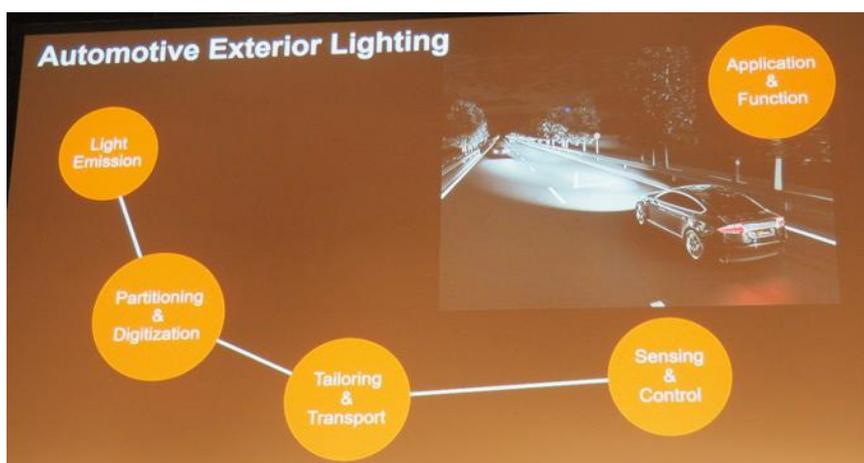
Light Sources and Sensors I

Chair: C. Allgeier (Osram Continental)

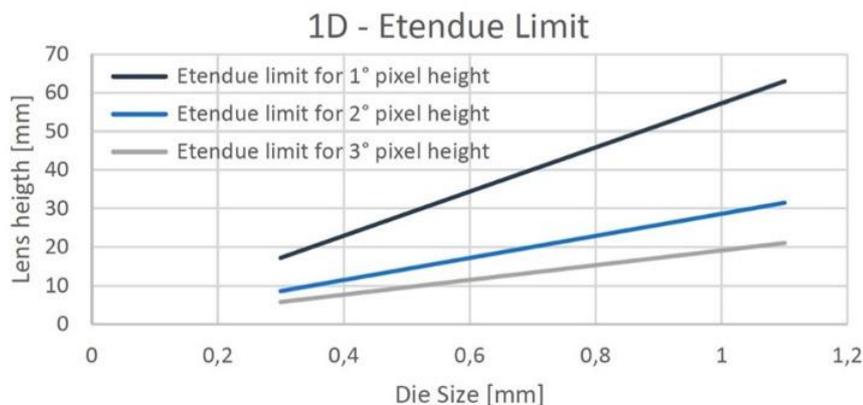
C. Allgeier introduced the session by showing the evolution from traditional vehicle lighting to digital lighting and in the future towards more light points and more connected headlights in the loop with autonomous driving systems.



To allow this evolution, light sources have to improve constantly and be strongly digitalised for integration with broader digitalisation trends. In parallel, the information given by sensors will be more and more important in lighting.



In lighting, there is a parallel improvement between functions and styling with improved performance and new functions accompanying low profile headlamps. These evolutions drive the development of LED sources along three vectors: high luminance, source miniaturisation and function integration.



High luminance for light sources is a key factor to reduce the optical system size as there is a correlation between optic dimension and source size, with a smaller die allowing for a smaller lens.

With a global efficiency of 40% to 55% for the complete optical system, a light output of 500 lm calls for a source of 1 mm² and luminance of 150 Mcd/m². For a light output of 2000 lm, 500 Mcd/m² would be necessary. 150 or even 180 Mcd/m² is reachable with the new generation of LEDs at 1.5 A for instance with the Lumileds Luxeon Altilon Intense Gen.2. Values like 500 Mcd/m² would need a much higher current and consequently a completely new design particularly for the epi active regions. Wall plug efficiencies over 30% will be needed at a power density corresponding to 8 A/mm². Naturally, heat dissipation and robustness will require new solutions.



Metrics	Target Spec 1x1	Target Spec 1x2	Target Spec 1x3	Target Spec 1x4
DC Luminance @Tc=85°C, 1.5 A	Typ.: 180 Mcd/m ²			
DC Flux @Tc=85°C, 1 A	240 lm (min.) 250 lm (typ.)	480 lm (min.) 500 lm (typ.)	720 lm (min.) 750 lm (typ.)	960 lm (min.) 1000 lm (typ.)
DC Efficacy @ Tc=85°C, 1 A	Typ.: 75 lm/W	Typ.: 75 lm/W	Typ.: 75 lm/W	Typ.: 75 lm/W
Light emitting area	~0.68x0.86 mm ²	~0.68x1.7 mm ²	~0.68x2.66 mm ²	~0.68x3.44 mm ²
Contrast	Enhanced	Enhanced	Enhanced	Enhanced
LED Tolerances @ 5 s	± 50 μm	± 50 μm	± 50 μm	± 50 μm
Reliability	AEC-Q102-RL	AEC-Q102	AEC-Q102	AEC-Q102

Matrix with direct imaging is another direction of light source improvement. To avoid primary optics necessary when the gap between dies is at around 0.5mm, Lumileds have the Luxeon Neo Exact with a 50 μm gap. The optical cross talk in linear arrays is reduced fivefold compared to conventional optical side-coat technology, a contrast gap centre-to-maximum-of-next-pixel of 1:200 in the centre, allowing direct imaging with a lens designed to smooth pixels.

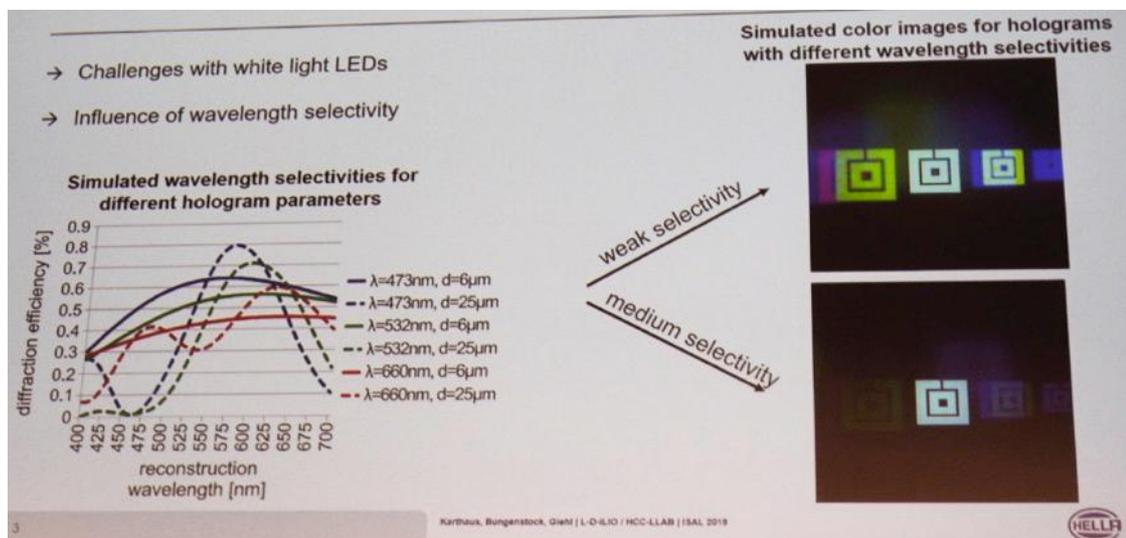
Digital beam is considered by Lumileds as the ultimate goal for integration. To achieve its benefits including lane marking and levelling, a resolution of 0.085° is necessary, and so around 20 megapixels with a pixel size of 0.040 mm and 0.46 lm per pixel. There are many challenges for that development including design compromise between pixel size versus light output, optical contrast versus light output, and pixel count versus chip size. Other challenges will be in relation to thermal management with roughly 50–60W in only 30-40 mm², extremely high yield, and tight quality control.

Challenges of the Illumination of Holograms With Narrow-Band LEDs in Auto Applications

Dr. D. Karthaus (Hella)

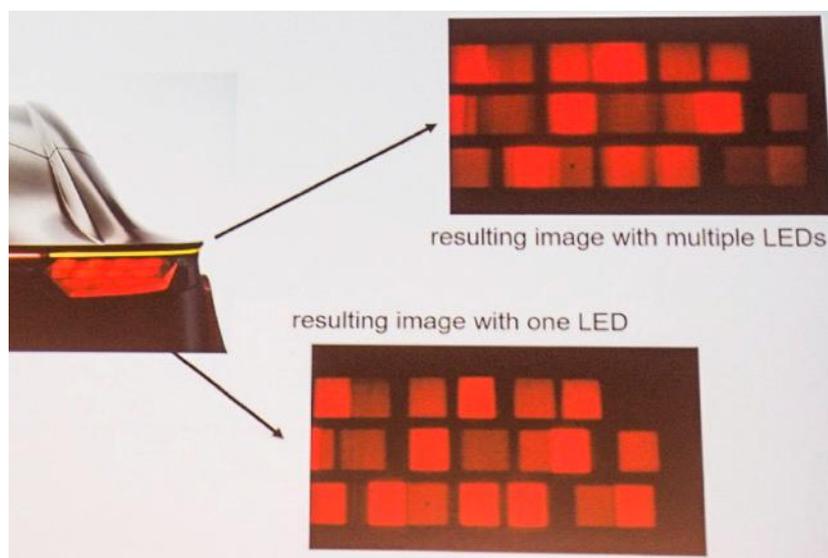
Holograms for signatures, 3D effects, or as optical elements show high potential, but the quality of the resulting images depends strongly on the characteristics of the hologram and of the reconstruction of the light source. In this presentation, the influence of the illumination concept on the reconstructed image was explored.

Selectivity is a key factor for a good enough image, this being a real challenge with white LEDs.



Hella analysed the behaviour of volume holograms with multi-LED illumination. In that case, the images were significantly blurred, confirming the theoretical approach.

A single LED illumination is allowing a much sharper image. However, when the light is crossing the holograms at an important angle for instance 60° , the efficiency is strongly reduced. A single LED can so only illuminate a small area at a reasonable distance.



As a result, there is difficulty to achieve sharp images with no ghosting. The main options to optimise images are collimation of multiple LEDs, adaptation of illumination distances, or adaptation of lateral LED position.

But all these options are not leading to really satisfying results, with high sensitivity to misalignment. Complementary work has to be done to optimise hologram use, particularly with an evaluation of new alignment concepts for the illumination with several LEDs, the optimisation of the 2D angular selectivity

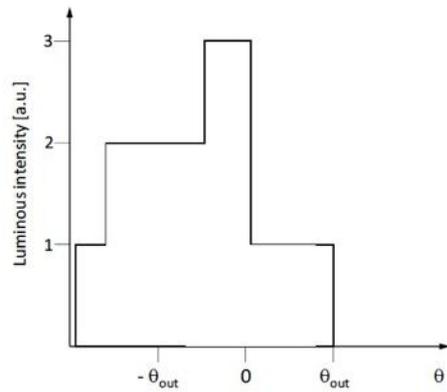
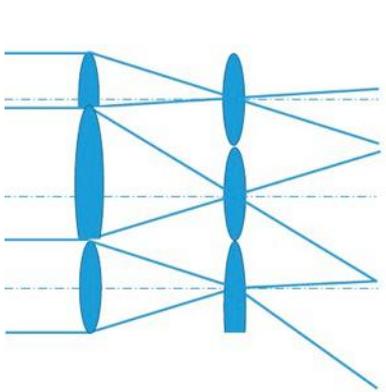
by adapting the recording, and the analysis of substrate thickness.

.Automotive Illumination Using Micro-Optics

P. Schreiber, Ch. Wächter, Ch. Li, D. Michaelis, St. Fischer, R. Leitel (IOF Fraunhofer)

Dr. Schreiber described the use of micro-optics to achieve miniaturised exit window and highly effective headlamps. Other interests of micro-optics could be its flexibility with simple adaptation to changing specifications and new degrees of freedom for artistic design.

A known multi-channel illumination optics is the fly's-eye condenser, but there is no continuous far field distribution with this system. An improvement was defined and used for instance in the BMW 7 for the welcome light carpet function shown at IAA 2018. The improvement compared to the previous solution was the use of an absorbing aperture mask, giving a good far field distribution with reduced efficiency.



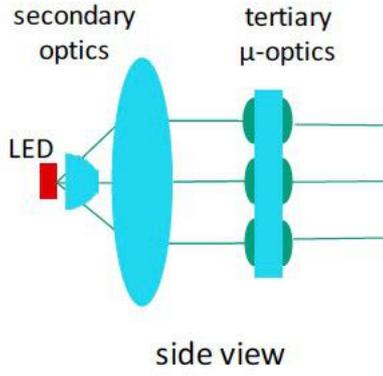
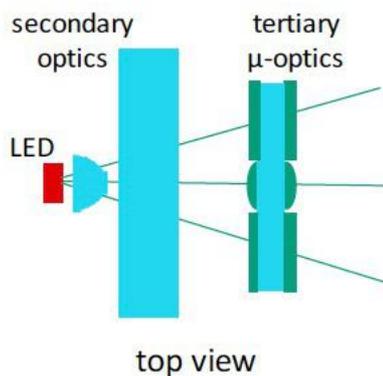
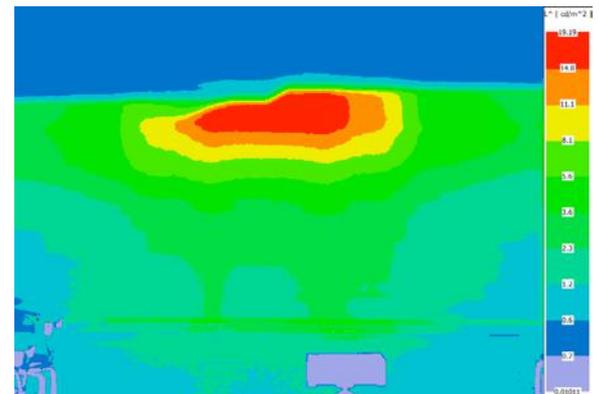
So, the target of the new development was to keep the good light distribution of an arrayed projector with good transmission as from the initial fly's-eye condenser. The new design integrates an irregular fly's-eye condenser (iFEC) as shown below with many advantages as entrance lenslets of different size, high transmission, high exit divergence, continuous far field,

skipped aperture layer and still etendue conserving.

A passing beam design was defined based on this concept naturally targeting the specifications of a low beam with a large divergence, a sharp cutoff, and an elliptical hot spot.

The principles of the design are the use of an anamorphic collimator to roughly shape the horizontal far field, two cylindrical lenslet iFEC regions for lateral spread, and rectangular lenslet iFEC for the central region.

A demonstrator was realised using Osram Ostar LEDs with two optical modules of $54 \times 40 \times 44$ mm. Another demonstrator is targeted with four modules of $30 \times 26 \times 32$ mm using Nichia NJ2W27OAT-Y7 LEDs. The first demonstrator with the two modules, housing and cooling has dimensions of $130 \times 70 \times 44$ mm. The transmission is as good as 65% and the maximum intensity is 35 kcd, with the whole beam conforming to UN Regulations. However, there is some stray light from spaces between the lenslets.



A high beam design was also realised using iFEC systems with a linear LED array with joint collimator. It has a global transmission of 37% and a total output of 570 lm with 11 W input and 50 kcd peak intensity. However, the diffraction causes some horizontal segment overshoot.

Durable Functional Coatings for Advanced Cleaning of Automotive Sensors and Headlamps
Dr. S. Wölper (GXC Coatings)

The necessity of clean sensors is obvious in the context of autonomous driving particularly for cameras. Similarly, it is important to keep the outer surfaces of headlamps clean in every condition. Cleaning systems are currently existing and the target of GXC is to improve their efficiency with a better lens coating.

This coating has naturally to fulfil all the numerous specifications of such a coating, for instance for transparency, adhesion to PC or PMMA, scratch resistance, no dirt adherence, cleanability and durability.

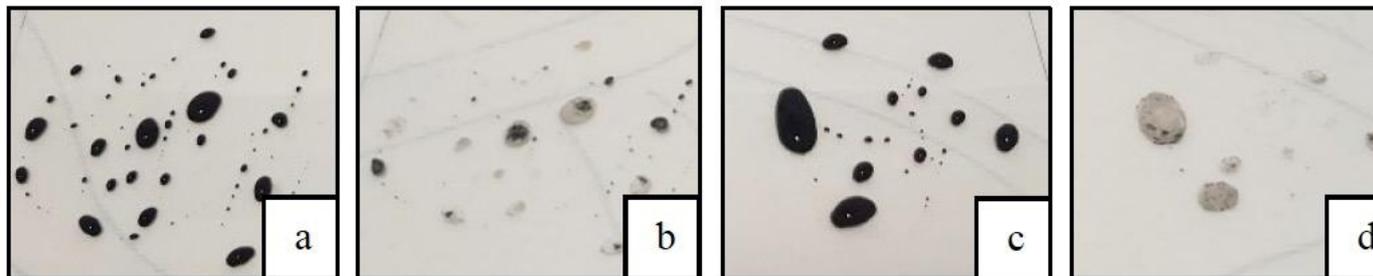


The new varnish was tested for scratch resistance after climatic cycling PV1200 20 cycles and obtained much better results (left) compared to commercially available hard coat (right).



Similarly, the results were better with tests for tree resin, dirt according UN R45, water, and insects. Images "a" through "d" show results for dirt suspension per UN R45. Image "a" is a commercially available hard coat with suspension; image "b" after drying and removal by compressed air.

Images "c" and "d" are the new coating in the same conditions.



		Conventional HC	GXC HC
Dirt	0.3 ml	13 s	3 s
Suspension	5 ml	3 s	2 s

So, the new coating is showing less residence time to build up adhering forces and reduced dirt adherence. For insect contamination, the results are also showing improvements compared to a conventional hard coating. This new coating must now complete tests particularly with cleanability in combination with headlamp cleaning systems as well as long term durability testing (the U.S. Florida/Arizona 3-year outdoor exposure tests).

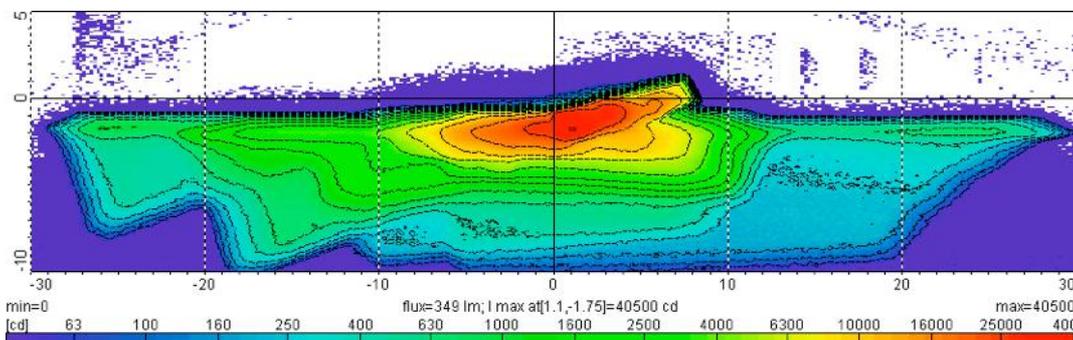
Heatsinkless Economic LED Headlamp Approach

S. Groetsch, M. Kiessling, A. Guenther, N. Haefner, R. Huber, (Osram Opto Semiconductors)

Onrunning evolution in LED efficacy have brought emitters providing more than 110 lm/w at 120°C. Practically: 400 lumens at 1 ampere, at room temperature. These levels of efficiency stand to facilitate new levels of affordability and therefore feasibility of LED headlamps. As the required power decreases, the thermal management task grows easier; this presentation centred on LED headlamps without heatsinks, and their knock-on effect (along with simplified driver electronics) of facilitating low-cost standard lamps.

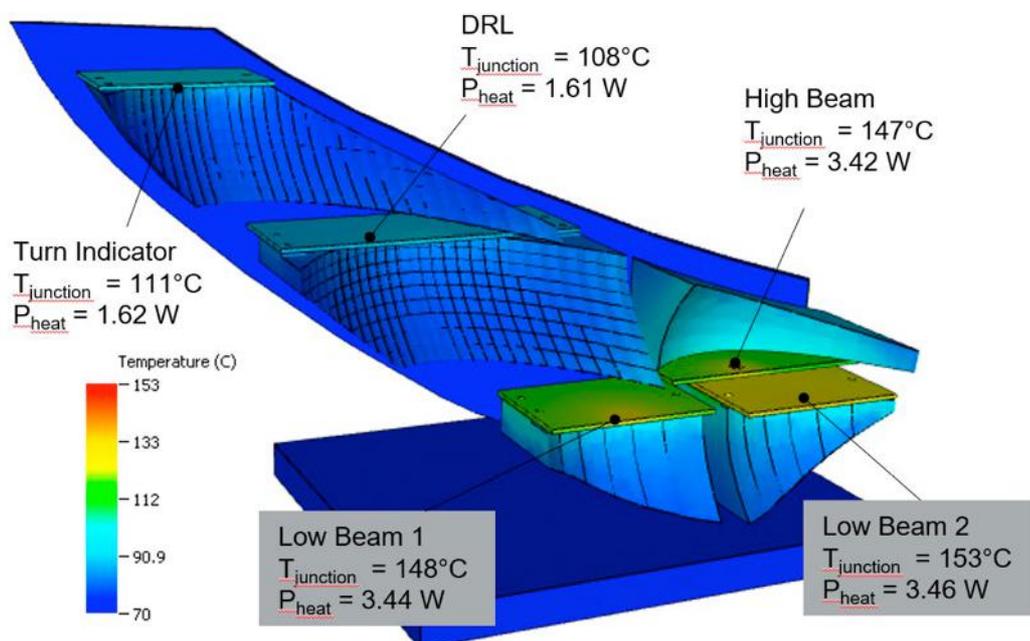
So far in the history of LED headlamps, there has been something of a choice between high efficiency with many LEDs operated at low current (with associated high cost) or low cost with few LEDs operated at high current (with associated high thermal loads requiring bulky heatsinks or other thermal management techniques). The researchers investigated whether it is possible to have all the benefits without the drawbacks from both approaches.

Research was carried out with a prototype multifunction front lamp (low beam, high beam, DRL, and turn signal). All functions used reflector-type optics. The low beam is provided by two reflectors, each approximately 72 × 42 mm and each having six facets. The resultant low beam pattern seems quite performant, with peak intensity of 40,500 cd and spread of approximately ±30°.



The single high beam reflector is about 98 × 41 mm and has seven facets. The high beam's peak intensity is 52,700 candela. All in all, for all functions, there's a total of eight emitters, each 1 mm²;

the researchers say this count can decrease as LEDs carry on growing more efficient. A buck-boost driver is used with all LEDs in series driven by the same current. Whichever light function is active is not bypassed by a switch component; all others are. The basic principle for thermal management is to make use of free convection cooling from the insulated-metal-substrate PCBs rather than providing a dedicated heatsink.

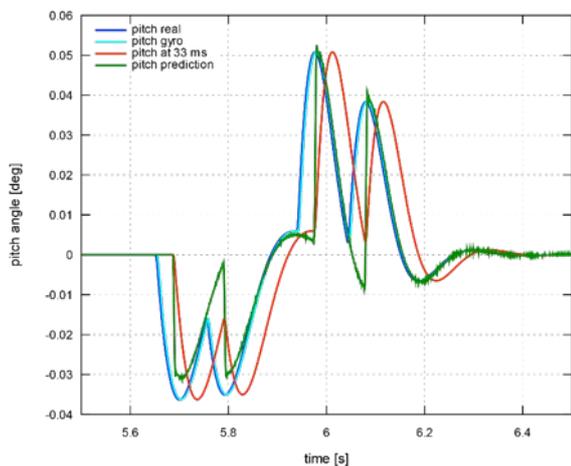


The thermal simulation involved a housing and reflectors made of plastic. With all LEDs lit, the main functions' junction temperatures are around 150 °C, while the signalling LEDs operate at around 110 °C.

Sensor Fusion for Dynamic High-Resolution Lighting

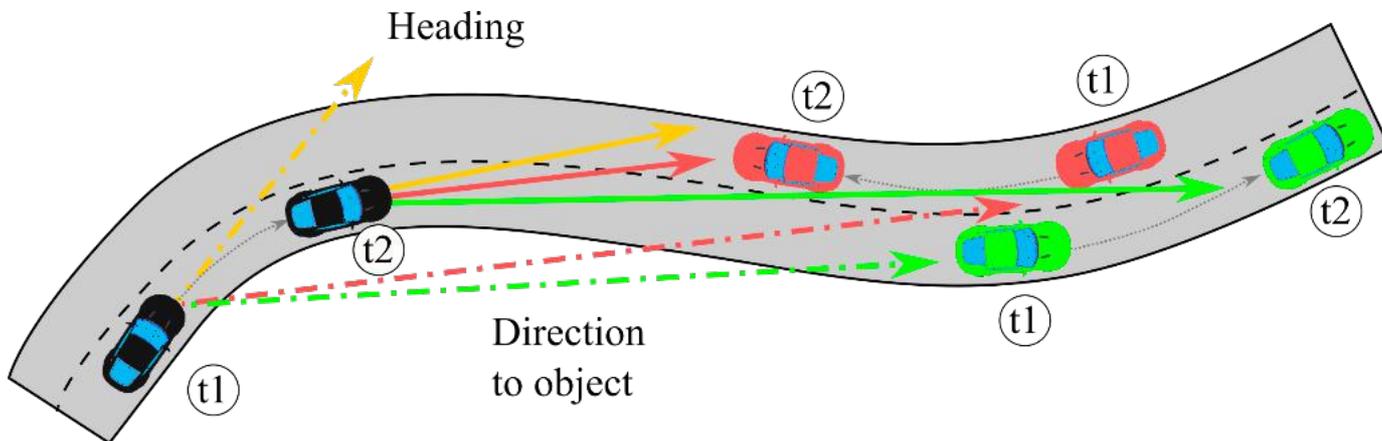
M. Austerer, M. Holzbauer, C. Künzel, M. Rosenauer (Osram Continental), A. Jachens (Continental Automotive)

This paper presents the researchers' work on improving high-resolution headlight system capabilities through detailed models of the vehicle's environment and its movement are obtained by intelligent sensor fusion algorithms, including latency compensation by predictive algorithms. Their end goals are to perform functions like real time low beam cutoff stabilisation, and high beam augmented-reality types of user experiences.



The authors describe the state of the art in headlight resolution, including a review of the various technologies and techniques used to attain high (and growing) resolution. They cite the Texas Instruments DMD setup as offering the highest resolution presently on the market. They discuss the benefits of high-resolution headlamps in terms of the real functionality of AFS and ADB systems. A practical example: the greater the resolution, the smaller and more precisely adapted can be the shadow zones in a glare-free high beam. Another: the low beam cutoff's visible bounce and jitter over bumpy roads can be effectively smoothed out, given low sensor latency and fast light system reaction. Moreover, the presenters review the

additional lighting functions unlocked by high-resolution systems; vehicle-width guidelines for construction zones, navigation information, and other projected-image ideas.



Resolution requirements for precision and latency are described in concrete terms of object size and distance. The need for safety margins (additional shadowed-out area beyond the actual edges of an oncoming car, for example) is described as mostly a function of system latency, the delay between a stimulus and a response. Countermeasures to system latency are discussed, namely predictive intelligent sensor data processing. The authors assert that the megatrend of automated driving helps push the development of better adaptive lights, largely on account of the abundance of sensors necessarily installed to allow automated driving. Sensor fusion will improve the functionality of existing lighting functions. Finally, the authors note that these beneficial effects can only happen if there is a strong push for lighting-specific sensor fusion and its associated software.

Development of Laser Scanning Headlamps Using MEMS Mirror Device

M. Miyachi, H. Kurosu, M. Sakurai, M. Tani, Y. Yasuda (Stanley Electric)

This paper starts out by noting that nighttime pedestrian fatalities have not been decreasing lately. The authors state their belief in the possibility of reducing pedestrian fatalities by optimally controlling light to give drivers the maximum possibility of recognising pedestrians. More specifically, the authors say that laser scanning headlamps can

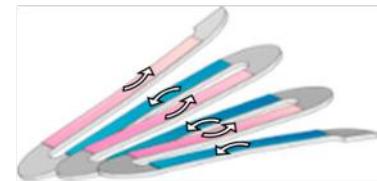
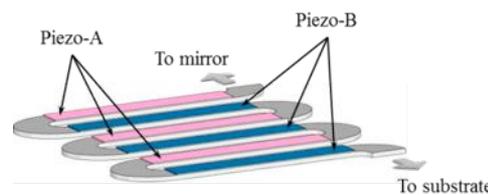


act as a countermeasure against pedestrian fatalities. They propose an optimised MEMS device to achieve the necessary light control.

The researchers review the advantage of an ADB system to resolve the conflict between drivers' need for seeing light and aversion to glare. They then go a step further by stating the possibility of not just masking out other road users from glare, but increasing light in specific

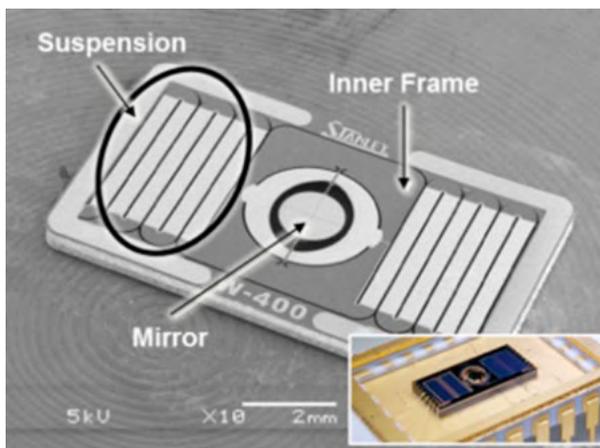
regions to show drivers what they urgently must see (e.g., pedestrians). They have developed a headlamp combining laser diodes with microelectromechanical systems (MEMS) scanning mirrors.

The novel MEMS mirror motion mechanism—piezoelectrically operated meandering cantilevers—is described in terms of its function, its advantages over other mechanisms, and its avoidance of vertical resonance that would interfere with the intended mirror motion.



Flexible light distribution is achieved by modulating the laser power in accord with the

MEMS mirror's operation. Other drivers can be shadowed out, and local illumination can be increased by decreasing the deflection angle of the MEMS mirror to limit the scanning range of the laser—which the authors point out as one of the major benefits of the laser scanning method over a DMD or LED array solution.



It is quite amazing to see the rapid evolution of advanced ideas in vehicle lighting. This is a phenomenal advance since the previous iteration of this line of research, just two years ago at ISAL 2017. The possibility to build hazard-highlighting and de-glaring into a single headlamp mechanism—rather than requiring supplemental light sources to do the

highlighting—is quite intriguing. And this nicely answers the question, current until recently, of the practical utility of a laser-based headlamp (which, when that question was asked, could shine light 600 m down the road but not do other tricks).

Digital OLED for Taillighting—Most Efficient, Homogeneous, and Flexible Display Technology

Dr. M. Kruppa (Audi)

Dr. Kruppa started his award-winning lecture by noting that OLEDs have been applied in vehicle tail lamps since 2016, and reviewing the attractive aspects of the technology: top-notch contrast ratio, smallest packaging, and high system efficacy. He noted that great progress has been made against obstacles like reliability and cost, and asserted that the progress is such that wider deployment of OLEDs is now feasible, and predicted that digital OLEDs will be at the forefront of highly-versatile V2X communications. All of this as background to his company's latest innovation: taillights featuring OLEDs on a bendable-glass substrate. Namely: Flexible-Digital-OLED.

Kruppa went into greater detail as to the reason for pursuing OLED development: LEDs' point-source characteristics mean surface-type illumination in signal lamps requires optical solutions to scatter the light. Homogeneous light distribution can be achieved, but optical efficiency is low and it is difficult to meet the required light distribution. Ongoing evolution, optimisation, and innovation means progress against these shortcomings, but the central incompatibility remains: the use of a point light source to illuminate a defined area. OLEDs, on the other hand, can perfectly illuminate across a defined area, to a degree not practically achievable with LED-based solutions. Moreover, the direct surface light characteristics of OLEDs unlocks the ability to have very sharp contrast between different active regions in an OLED panel within very small distances. Specifically: individually-controllable segments with sharp cutoff and small separation distances between them can be achieved within a single OLED, without light scatter, crosstalk between segments, or other optical noise.

To fully leverage these advantages intrinsic to OLED technology, Audi and their suppliers are making highly-segmented OLED displays—at least 50 segments per OLED tile—using existing processes and materials, while meeting all automotive reliability requirements. The large number of segments makes it possible to digitally change the lit shape and appearance of the taillight. The implication here is that one OLED module can be used in many different cars, each with its own individual design—a much less expensive way to do it than creating an OLED module specific to each and every car.



On the OLED module, each segment can be individually designed; there is no constraint to a grid-type pattern. Therefore, precise patterns can be created by shaped segments, rather than building an image out of dots or pixels,

which requires complex driver electronics and imprecise image edges. Another implication of this ability is that high-performance car-to-human messaging becomes possible. Moreover, high luminance and deep red colour are already possible, to a degree greater than display-based solutions.



Another technical breakthrough described by Dr. Kruppa is the use of flexible substrates. Up to now, OLED tail lights have used flat glass substrates, which introduces constraints on the design because only those designs capable of being made 3D using 2D components could be realised. This was not acceptable to Audi designers, who wanted the OLEDs to curve and wrap in accord with the vehicle's body lines. With bendable glass it becomes possible to create a truly 3D OLED module that conforms to the car curvature. Kruppa ended his talk with the bold statement "The revolution has just begun".

Adverse Weather Light—New Approaches to Evaluate Adaptive Light Functions

A. Thoma (L-Lab), M. Vollrath (TU-Braunschweig)

This lecture reported on experimental efforts to address one of the use cases not adequately catered for by current-production adaptive headlamps, which do a fine job in good weather. But inclement weather conditions such as fog or snowfall cut seeing distance, depriving the driver (human or machine) of crucial information needed to make the right driving decisions. The goal is to leverage the potential of high-resolution headlamp systems to provide optimal visibility in bad weather. The basic intent in foggy conditions, for example, is to achieve high object contrast while minimising backscatter and its resultant self-dazzle.

The authors go into the defining aspects of roadway illumination for various atmospheric conditions. In light fog when the low beam range is inadequate, the cutoff could be raised to provide greater distance reach without the



above-horizontal high beam light that would cause backdazzle. In heavy fog, the cutoff could be lowered. That amounts to lowering the amount of light above the cutoff; another strategy is to increase the amount of light below

the cutoff. Another approach would be to have the nearside headlamp produce more light and the offside lamp produce less, with the overall output the same. This would reduce scattered light in the driver's direct sight lines. Also, foreground light can be reduced, and different kinds of asymmetry can be realised: strong lateral light, for example, with reduced straight-ahead light. This is all easier to achieve now than ever before, with high-resolution headlighting systems.

With so many different strategies, which ones work best? That answer was not the goal of this work. Rather, the experimenters meant to find a reliable, practicable way to evaluate adverse-weather lighting. They put together three studies, one with artificial fog and two with natural fog, focusing on the driver's subjective feeling of safety and on objective, measured real seeing distances. Participants drove a test car with high-resolution lighting in fog. Two different light distributions were presented, and participants had to pick a favourite. The authors note the great difficulties in getting reliable, comparable results in an inherently unstable and unpredictable condition such as fog, and recommend conducting studies in artificial fog as it is most conducive to obtaining objective measurements and reproducibility.

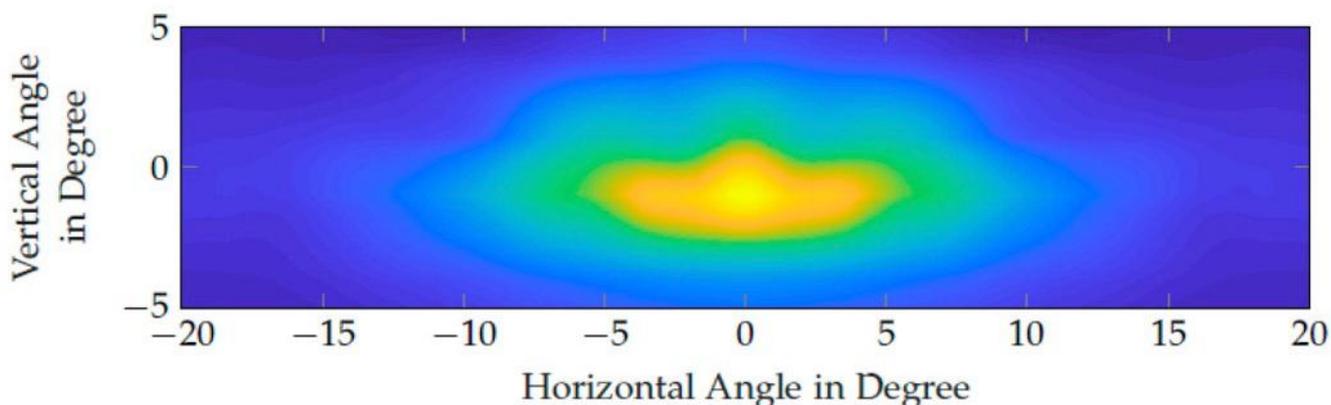
Object and Gaze Distribution Based Optimization of Low and High Beam

J. Kobbert, K. Kosmas, T.Q. Khanh (T-U Darmstadt)

The researchers here noted that although a great many adaptive headlighting systems are now on the roads, with more being commercialised all the time, the basic light functions and beam distributions have not changed. In response to this, they propose a new method of optimising light distribution based on traffic and driver-gaze behaviour. Their research involved 54 test subjects and a total of more than 6,000 km of night driving on city and country roads and motorways. Gaze direction, illuminance at the driver's eye, and the distribution of other road users and traffic signs were recorded. All the resultant data was integrated to arrive at a new light distribution.

A tensor flow network was used on the data. To train it, 500 captured frames were manually marked, then used to train and test the network. 70% of the marked data was used to train the set; the remaining data was used to test the network. Accuracy generally ranged from 25 to 65 percent, with the low end of that range applying to traffic signs and the high end to other cars on the road. Eye tracking data was treated differently and greater accuracy rates were attained. Some interesting findings accrued from the eye tracking data: it provided results in accord with most all previous such data, contradicting only one previous finding.

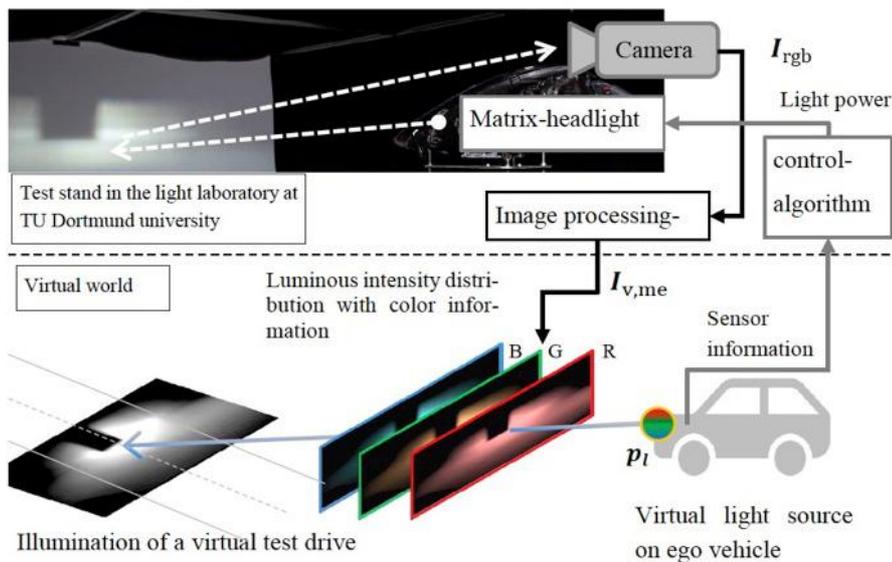
Perhaps one of the most interesting outcomes of the research is the result of combining and processing the collected data in appropriate ways defined by the researchers. The result is what the researchers call an optimised light distribution based on contrast measurements for detection, object distributions, and gaze directions. That light distribution, which is produced here, bears a striking resemblance in overall shape to a traditional US (SAE) headlight beam pattern:



The researchers point out that while the optimised and conventional beam patterns have about the same intensity at H-H, the optimised beam pattern is significantly more intense at 0.5°D, and the optimised beam pattern contains substantially (50%) more light flux.

Evaluation of the Light Distribution of a Matrix Headlight With Hardware-in-the-Loop Simulation (M. Waldner, T. Bertram (TU-Dortmund))

This paper presents a new method for evaluating high-resolution headlighting systems using hardware-in-the-loop (HiL) techniques, in response to the increasingly steep challenge of modelling and virtually developing and testing headlamps as they grow more sophisticated and higher in resolution and capabilities. The described system digitises the light distribution of headlights in real time, and then applies it to illuminate virtual testing scenarios. The digitised light distribution matches the actual light distribution in intensity and colour, making this approach applicable to headlamps with varying levels of resolution and different technologies. The authors point out that the HiL method is key to reliably being able to virtually evaluate a headlamp system in real time at any daytime under reproducible conditions".



The first step is digitising the light distribution by means of a camera system. An algorithm evaluates the captured images and calculates the luminous intensities. The resultant virtual beam is used to illuminate a virtual test environment. Then the real headlamp's light distribution is adapted to the virtual scenario—that's the closed test loop, and it allows iterative testing of the headlamp in scenarios that can be difficult to attain once (let alone multiple

times) in the physical world. The use of the real headlamp as the light source minimises assumptions and simplifications, thus improving the fidelity and resultant dependability of the simulated tests. The resolution of the imaging camera is the limiting factor.

The paper goes into close mathematical and technical detail on the steps and processes involved in the visualisation, imaging, calculation, and simulation method, noting that it is iterated for red, green, and blue channels. The overall accuracy of the real-time visualisation is $\pm 20\%$ on high beam full scale. Blue edges of the light distribution caused by chromatic aberration and the inhomogeneities caused by the pixel overlap are visible in the camera data, and these kinds of brightness and color gradients within the light distribution are reproduced realistically in real time in the simulation.

Applications for the method include virtual test drives, headlamp system development, and detailed analysis of nonstandard operational modes—failure simulation, for example, or the effect of different kinds and degrees of lens occlusion by different kinds of dirt, or failure of any number of light sources within the lamp. The influence of any such thing on the headlamp performance is readily visible in the virtual environment. Another application: stress-testing the headlamp in different environmental conditions.

The technology also applies to very-high-resolution forward lighting systems; it can be used with a 2-megapixel beamer to simulate the road projection abilities of a DMD headlight system, for example. Here again, the camera is the limiting factor in the fidelity of the virtual light performance. The authors state that multi-camera variants of their system are under development, so as to increase the system resolution and

allow for slow-motion videos to detect flicker from the system under test.

Digital Light—The Future Light Distribution for Automated Vehicles

C. Gut, Z. Xilu, B. Boeke (Daimler)

This lecture describes the roles headlighting systems must fill for successful automated driving, with emphasis on how Daimler's "Digital Light" system works toward safe nighttime automated driving. Basically: the visual task of "seeing the road" has always involved much more, for human drivers, than just perceiving the road itself (the strip of pavement). Like layers of an onion, the task is revealed to be complex: the driver must see the road, the markings on the road, the signs governing usage of the road, the pedestrians and bicyclists and other motorists using and approaching the road, obstacles in, potentially in, and near the road; the ambient conditions (light levels, weather) that will affect the safe use of the road (such as fog, shown in photo), and so on and on. All of this applies equally to machine drivers: the headlights must support the visual sensor chip of a camera to do all these

same tasks, and possibly more.

The authors point out that the human driver's senses are effectively replicated by all sorts of sensors, algorithms, and technologies to make decisions. The visual sensors, they say, analogous to human eyes, are crucial because they have the greatest spatial resolution and can provide a vast amount of



information like the shape, size, and colour of objects, they can read traffic signs, etc. They note that Tesla have claimed a purely visual sensor system will get the job done, while Ford have claimed the opposite: lidar and radar suffice without cameras or headlights. The Daimler team assert that in truth, adequate reliability demands a system with radar, lidar, *and* visual cameras, and that perhaps the most important role of the visual camera/headlight system is to support the sensor network of an AV by detecting objects, colours, and weather conditions at night. Examples are given where inadequate AV vision caused or contributed to crashes.

At night, AVs must be able to detect rain, fog, snow, and rain-slick or frozen roads. This can be done perhaps adequately by ambient light during the day, but at night headlamps are surely necessary. The authors note the paucity of research into the specifics of this area, and give an example of how an advanced lighting system can directly meet the needs: the Daimler Digital Light system, they say, can support the detection of bad weather by illuminating a specific region of interest, then measuring the intensity of the reflected light—thus providing a measure of fog density. Rain and snow detection can be added by assessing the degree of busyness, flow granularity, and regularity; meanwhile, the road surface conditions can be kept track of by reference to the headlight reflectance on the street.

Finally, the authors predict that evolution will bring closed-loop operation with cameras and headlamp systems controlling one another to optimise illumination *and* machine sensing.

Session: AV Signalling

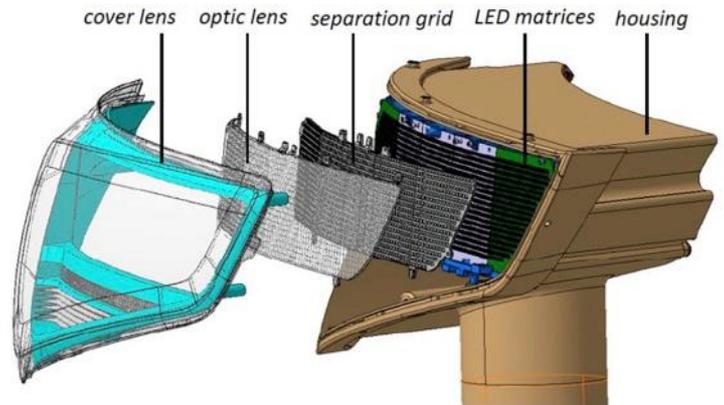
Customizable Pixel Signal Lighting

Dr. S. Knoop (Hella)

Dr. Knoop presented Hella's approach for a display for stop and tail function that is achieving automotive specifications, usable for V2X communication and with a non-planar geometry for a better aesthetic integration.

The current conventional displays available today are not able to achieve these specifications. New solutions have so to be developed.

The one developed by Hella here has two monochrome displays with 1,647 individually controlled LEDs—1,473 red ones for the stop/tail functions, and 174 yellow ones for the turn indicator; the pitch between LEDs being 4 mm.



The design includes PCBs with LEDs, a black separation grid to avoid stray light, a curved optic lens with inner lenses in pixel size that collect and collimate the light, and outer optics (cover lens) as micro or diffractive optics for light scattering and to achieve a good light distribution.

For animation design, Hella developed a specific tool called "GAIN" for Graphical Animation INterpreter. The approach is to describe the required animation within the virtual coordinate system based on the "animation objects" and their transitions from one state to another. Commonly used video cutting tools can be introduced and then simulated with 3D visualisation. This software is optimised for efficient real time computation of light animations. It uses object base format automatically generated by GAIN to describe the animations and to compute the required control values during operation. This idea is particularly helping to save memory space.



Naturally as seen above, the system can display any kind of shape for stop and tail function, including new functions for communication or fun.

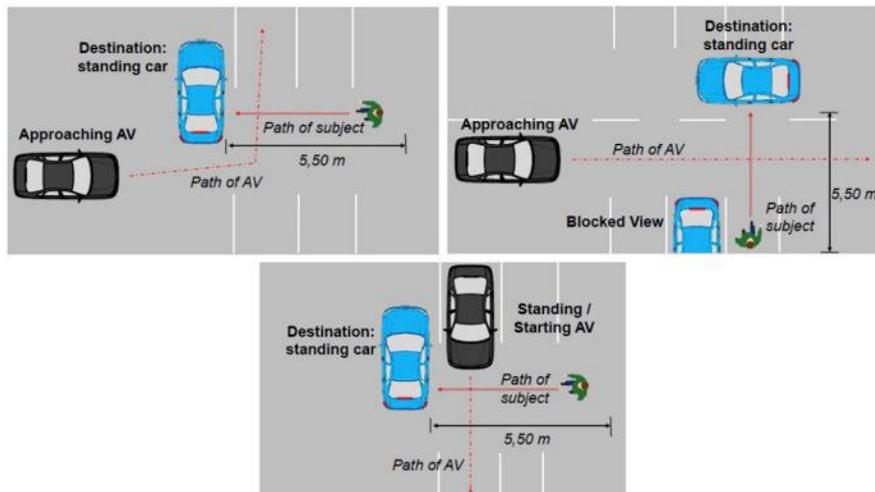
The potential for safety-beneficial performance is intuitively obvious but has to be supported by strong studies to convince administrations to allow for their deployment. Naturally, cost of these systems will have also to be accepted by customers.

Investigation and Comparison of Pedestrian Behavior in Different Encounter Scenarios with AVs
T. Singer (TU Darmstadt)

This study looked at situations with an automated vehicle and a pedestrian in a parkade. The target of the study is to define the best understood signals that can be emitted by AV for pedestrians in different situations in a parkade to try to replace some signs that human drivers can give to pedestrians to inform them about their intention.

Three different encounter scenarios are tested in the parkade:

- **Parking:** The pedestrian walks along the lane and the AV approaches from the front and turns into a parking space
- **Passing:** The pedestrian crosses a lane and the AV approaches from the left.



- **Deparking:** The pedestrian walks along the lane and a standing AV starts driving out of a parking space from the right. For each of these three scenarios, three velocity phases were considered: driving, waiting and starting, so globally nine situations. Three displays attached to the front of the vehicle gave information to the subjects through three types of information for each use case.

For each use case, the subjects had to say if the intention was clear, if they felt safe or if the vehicle posed a danger. Each sign was then assessed.

The conclusion of the study is that for the subjects (18 people from 19 to 41 years old), symbols provide a better recognition of the intention of the driver and a better safety feeling. Furthermore, uniquely identifiable symbols are rated best.

Scenario	Symbol	Intention clear	I feel safe	Vehicle poses danger
<i>driving</i>				
parking		4	3	2.5
		3	3.5	2
		4	3	3
passing		4	4	2
		2.5	3	3
<i>waiting</i>				
parking		5	4	2
		4	4	2
		4	3	3
passing		5	5	1
		2	3	3
		2	3	3
departing		4	4	2
		4	4	2
		1	2	4
<i>starting</i>				
parking		5	4	2
		5	4	2
		4	3	3.5
passing		5	4	2
		5	4	2
		3	2	2.5
departing		5	4	2
		2	2	4

Light-Based Communication of AVs With other Traffic Participants— in a VR Environment C. Kettwich, J. Dodiya, M. Wilbrink, A. Schieben (DLR/German Aerospace Centre)

This study was realised by eight industrial and academic partners in four countries and was funded by the EU to the tune of €5.5m. The main target was to investigate the interaction of an automated vehicle with a pedestrian, by dint of virtual reality systems. The AV was equipped with six variants of external Human-Machine-Interface



(eHMI), realised with a LED band outside of the vehicle and a directed lamp installed behind the windshield in the position of the rearview mirror.

The LED band outside the vehicle gave different combinations of lighted areas depending on the message. These eHMI are used to present information for a perception based or for an intention based or a combination of these two design strategies.

Intention-based interaction strategy provides information to other

users about next manoeuvres, while perception-based interaction strategies give explicit information to other traffic participants that they have been detected. One first question was which strategy pedestrians prefer, and a second was if there a difference in preferences across different driving scenarios.

An experimental setup was realised using a virtual reality pedestrian simulator with a VR headset and with scenarios implemented in an unreality engine. Every participant can move freely in VR. The 27 participants were in urban scenarios with mixed traffic situations and the AV communicates with an eHMI. Each participant wants to cross the road and makes the decision to cross in three scenarios: crossing, intersection, and parking.

The intention to decelerate was signified by the light band progressively "shrinking" until it was totally dark. Conversely, for acceleration the light band was progressively filled until the whole light band was illuminated.

For perception of pedestrian, a specific segment was illuminated in the direction of the pedestrian in the LED light band and the lighted segment moved to follow the position of the pedestrian.

The findings: perception-based strategies are ranked higher than intention-based strategies, and the most preferred are the combination of the intention- and perception-based strategies. Notably, the scenarios have no influence on the preferred interaction strategy. Next, this study will be confirmed by an evaluation of interaction strategies under test track and real-life conditions.



'I Have Detected You': Perception-Based Interaction Strategy for Automated Vehicles

M. Kaup (Hella)

This presentation described an eHMI approach of a pure perception-based interaction strategy of AVs with human users (HRU) with only one explicit message: "I have detected you". Messages can be classified in four groups: AV status, next manoeuvre, perception of the environment, and negotiation capabilities. Previous studies found that the most important for human is whether they are detected, and so this study focused on that message—the AV exclusively signalled that it had detected a relevant traffic participant (TP) and will take them into account within the respective trajectories.



The technical approach for the perception-based interaction was the choice of two eHMI solutions developed, implemented and integrated into demonstrator vehicles.

The first is a 360° LED Light band visible for all. The light band is a direct-emitting, roughly horizontal ring around the vehicle which can be illuminated completely or segmentally, allowing different interaction

strategies.

The second solution uses a directed signal lamp, visible only for specific TPs. One of the important characteristics of this lamp is that the message is sent to the specific direction of the targeted TP, and not in any other direction.

The researchers concluded that there is still no final answer on best interaction strategy on AV with HRU in mixed traffic and that to get this answer, all different interaction strategies have to be compared within studies against each other. Naturally, a pre-condition is that AV must be capable of object detection and classification, still not yet achieved.

How Important is Communication Between Automated Vehicles and Other Road Users?

B. Zandi, J. Scheer, T. Singer, D. Polin, T. Q. Khanh (TU Darmstadt)

The key topics of this talk are which messages an automated vehicle should be able to signal, and how important communication is at all. 76 subjects from 19 to 59 years old assessed the importance of messages in different phases encountered between AV and pedestrians. In each phase, the investigated messages were: "I drive autonomously", "I have seen you", "I do not pose any danger", "I would like to continue my drive", "Warning, I am dangerous", "I continue now", "I'm accelerating right now", "I'm slowing down", "Thank you", these messages

Summary of the results – Median values

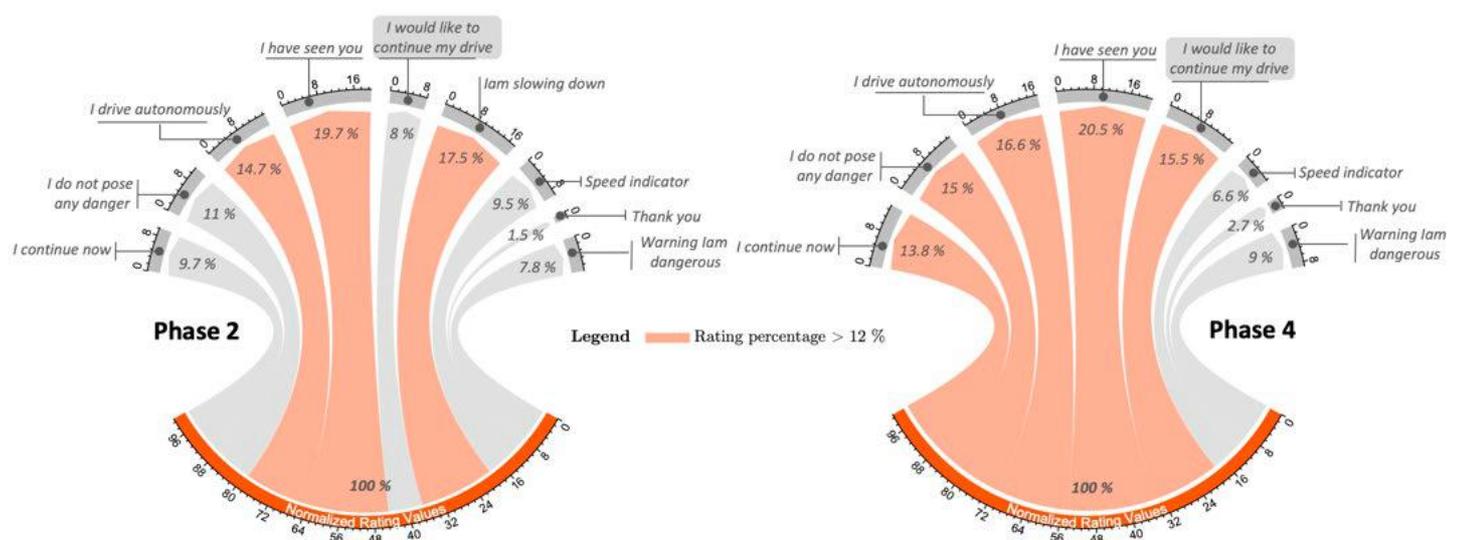
	Phase 1	Phase 2	Phase 3a	Phase 3b	Phase 4	Phase 5	Σ Rating	Color coding
„I drive autonomously“	7	6	5	5	7	5	35	✓
„I have seen you“	8	9	8	7	9	4	45	✓
„I do not pose any danger“	3	5	5	6	7	2	28	✓
„I would like to continue my drive“	5	2	3	3	7	5	25	✓
„Warning, I'm dangerous“	2	2	0	0	2	2	-	✗
Speed indicator	3	4	0	2	1	2	-	✗
„I'm accelerating right now“	-	-	-	-	-	8	8	✓
„I'm slowing down“	-	8	-	5	-	-	13	✓
„I continue now“	6	-	3	5	5	8	24	✓
„Thank you!“	0	0	0	0	0	0	-	✗

Color coding
 If Rating ≥ 5
 If Rating < 5
 Intention messages
 Intention messages

being rated in a scale from meaningless at 0 to very important at 10.

Three messages are rated <5 in every phase, and so are less important. The top-rated messages are "I have seen you" and "I drive autonomously". Next, the subjects expressed their views on how important is the communication in different situations: daytime, distance from AV to the human road user, number of pedestrians, direction of communication to the outside, age group of people.

The main results: the importance of AV-communication is independent of the number of pedestrians; up to a distance of 10 metres AV communications are rated important, and beyond that distance AV communication was not considered important. This study is now continuing with 127 participants in China, South Korea, Japan and Germany.



Session: General Topics II

4K Pixel Solid State High Resolution Glare Free High Beam

Chair's Speech by Dr. S. Cladé (Valeo)

Increasing the number of pixels to a few hundred will show some progress, but the real breakthrough comes with the high resolution 4k pixel glare-free module which offers the ultimate adaptive lighting experience. With a resolution of 0.25° in both directions the full digital adjustment of each pixel intensity of the 4k module allows perfect homogeneity in all situations.

At the top, 4K Pixel Solid State Glare Free High Beam

With the Monolithic LED solution, light is directly removed from the light source itself and not cut by an intermediate digital element as it is the case for DMD and LCD modules. There is thus no unnecessary power dissipation to be managed in the module.

The fluidity of the movement of the edge of the glare-free zone can indeed be adjusted by digitally changing its sharpness. This allows making the junction between lit and glare-free areas more or less visible, and thus the perception of the function from the driver from smooth to more dynamical.



The calculation of the size of the glare-free area is linked to different parameters of the lighting module, mainly the pixel pitch, and the pixel edge blur defined as the angular distance between $0.5I_x$ and half of the pixel maximum intensity. The edge blur is slightly smaller to the one which is possible to reach in other already-existing Matrix and pixel systems. However, in other matrix systems, the precision of the

position of the glare-free area edge is worsened by the pixel pitch, creating on average a glare-free area which is larger, so decreasing the visibility.

The module is composed of four major components corresponding to the main functions

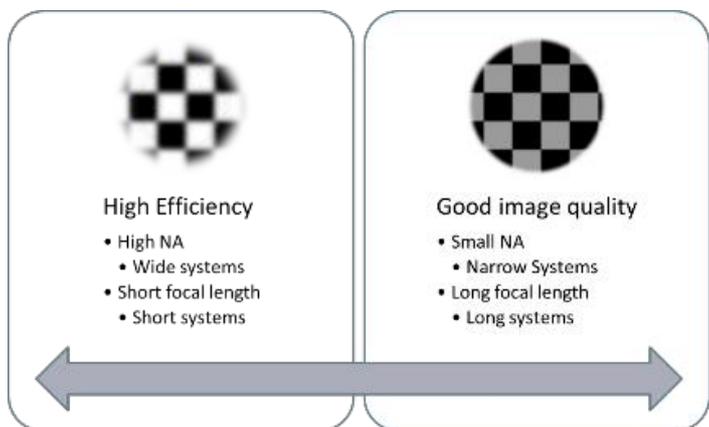
- Monolithic light source to emit light.
- Projection optics to project the light emitted by the source
- Cooling system to evacuate the energy emitted by the source
- Electronic board to drive and power the LED

The target of the projection optics will not only be to collect a maximum of light and shape it into a beam but also as imaging system to preserve resolution and contrast of each pixel. On an electronic system point of view, it is not possible anymore to drive each pixel individually but those thousands pixels will require to create the right image providing a homogeneous high-performance and dynamic light distribution by combination between Right Hand and Left Hand.

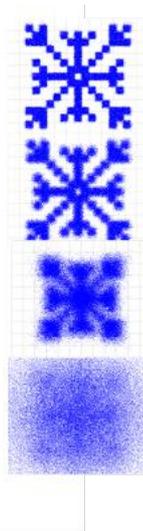
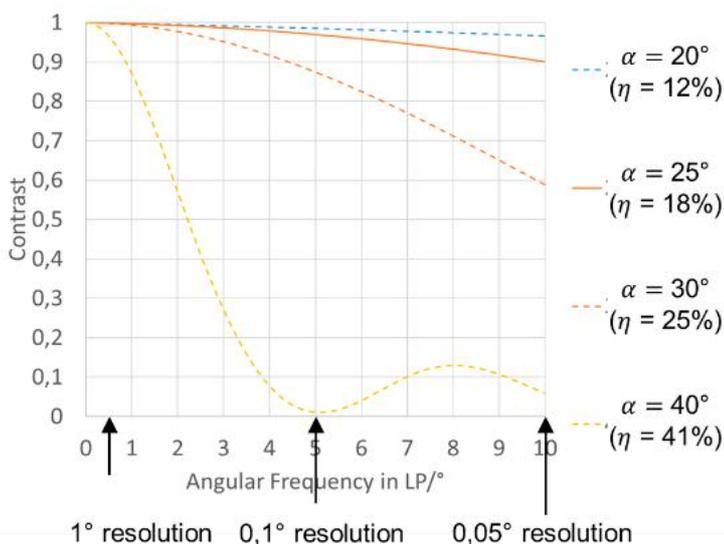
The 4k Pixel module is optimally specified for ADB, creating a very comfortable and performant lighting, all in a small-size lens and module package. In addition to lighting, such a system can already offer some basic image projection functions. The next challenge for this technology is increasing the number of pixels to 10 000 per module, thus reaching a pixel pitch of 0.1° .

This paper explains present challenges due to the transition from non-imaging to imaging optics.

It shows how acceptance angles of imaging systems affect efficiency and image quality. For image generating



elements there is no clear preferable system. Systems like LCD and DLP require more parts than direct emitting sources like HD-SSL as the light must be collimated for the image generating device. This results in bigger systems and more initial light loss. On the other hand, this also generates smaller divergences. With decreasing divergence better image quality can be achieved even with very simple im-aging optics, e.g. the 5° divergence of the LCD system only requires one lens to achieve an appropriate image quality.



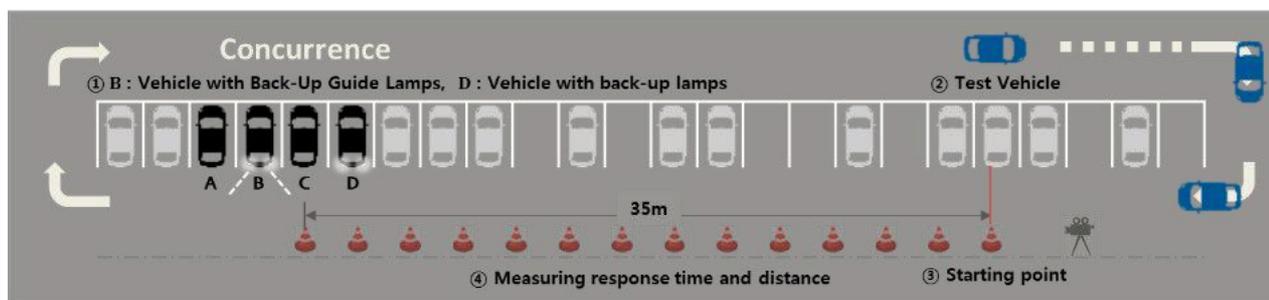
A tradeoff between efficiency and image quality is necessary. Rating image quality with MTF is possible, but the image generating element should be considered and for physical correct values (e.g. for automotive glare requirements) non-sequential simulation is indispensable. Considering tolerance sensitivity will help choosing the right optics also with respect to production costs.

Safety Enhancement Effect of Back-up Guide Lamps: A Field Experiment With North American Consumers
H. Pak (Yeungnam University), J.W. Hwang, K.B. Lee (SL Corporation)



To confirm the safety enhancement effect of back-up guide lamps (a light signal projected on the road surface rearward-outward from the reversing vehicle), such lamps were installed on the rear bumper of the test vehicle and each lamp projected a dotted line of 45 degrees downward and outward on the road surface. Sixty Americans participated in a field experiment and a questionnaire survey to compare back-up lamps (BUL) with back-up guide lamps (BUGL).

In all the scenarios, the response time and stopping distance in case of BUGL was shorter than with just BUL, which implies that BUGL is easier for an approaching driver to see, recognise and then stop in time. BUGL may be relatively more distracting due to the larger projection and reflection area compared to the BUL. According to the response data, however, BUGL does not have an adverse effect on a driver. Additionally, BUGL's qualitative ratings are higher than quantitative ones in perception, preference, satisfaction and purchasing intention.



The researchers conclude BUGL will help improve driver visibility and safety compared to just BUL. BUGL is now installed on the Hyundai Genesis G90 model in a market where it is permitted, and it is getting good response from the consumers—just like the research results.

Yuichi Shibata talks about the required luminous intensity of road projection lamps to inform crossing pedestrians of an approaching vehicle. He describes a road projection lamp in conjunction with a turn signal lamp to reduce traffic accidents involving collisions with cyclists and pedestrians. Specifically, he indicates the required luminance contrast that is necessary for both pedestrians in the vicinity of a car and cyclists to detect the road projection on the road. Experiments were conducted from weak daylight to nighttime. If the luminance contrast between the road projection and background is more than 0.22, a pedestrian using a smartphone can recognise the road projection under weak daylight. The value of luminance contrast is lower than the results of past experiment. It is easier to recognise road projection under low luminance contrast because of the colour difference between white and amber.

Half of nighttime accidents occur at intersections. In terms of behavioural situations, about half of the accidents happen when the vehicle collides with another road user while entering an intersection or hits another road user while turning left or right. In terms of accident types, the ratios of accidents between a four-wheel vehicle and a pedestrian, motorcycle, or bicycle are on the increase. One of the causes of accidents at intersections is that vehicles, pedestrians, motorcycles, and bicycles fail to notice other road users' movements. We assumed that the new lighting function of road projection could help them communicate to each other their intention and moves more effectively, thereby helping reduce traffic accidents. In this study, we focused on a road projection lamp that, when the vehicle is about to turn left, projects signs in sync with the turn signal lamp to experimentally determine the brightness (luminance contrast) necessary for other road users to notice the road projection not only at nighttime but in weak daylight as well.

The accident scenarios considered in this study were in the scenario A: "While turning left at an intersection, the vehicle risks hitting a motorcycle squeezing alongside, going straight ahead" and in scenario B: "While turning left at an intersection, the vehicle risks colliding with a pedestrian traversing the crosswalk".

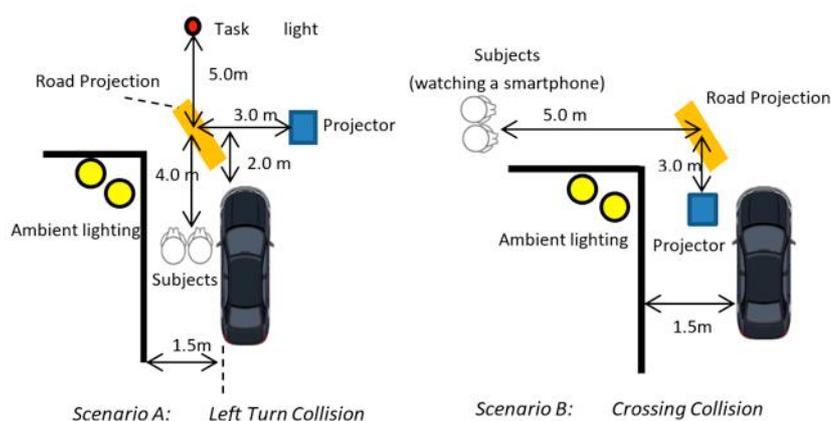
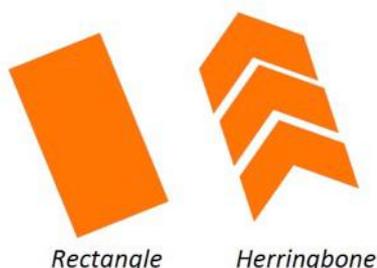


Figure 2 : Experimental Arrangement

Experimental condition

• Two projected patterns are analysed: rectangle and herringbone



- Ambient illuminance : 10, 50, 100, and 800 lx
- Five conditions of the brightness of the projection

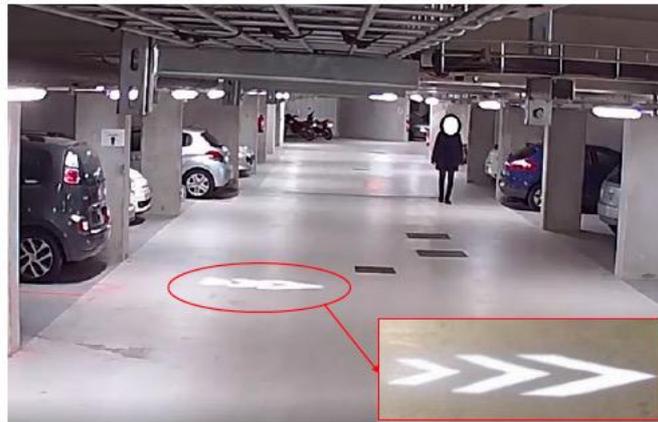
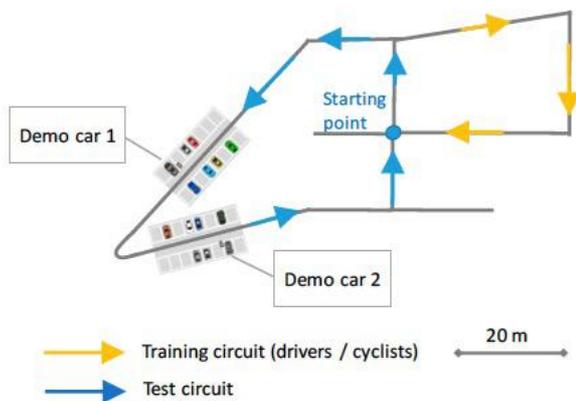
Under different brightness, pattern, and ambient illuminance of road projection, each subject answers 40 conditions about their sensory evaluation. Further, experiments were done to measure how quickly the subjects noticed the vehicle turning left with only the turn signal lamp flashing, according to each scenario and at various levels of ambient illuminance.

In the situations assumed in this study, people do not notice an approaching vehicle in weak daylight condition, even if the vehicle flashes ordinary turn signal lamps. The lamp luminosity that allows all road users to notice the road projection under the experimental conditions in this study was 6,350 cd for a projection distance of 3 m and an installation height of 0.7 m.

Impact of Advanced Lighting Function Based on Road Projection for Departing Indication in Parking Lots

S. Azouigui, B. Barbedette, S. Saudrais, Y. Sortais, (ELS–ESTACA) , S. Bordel (Cerema), C. Neumann, P. Jahn (KIT)

The study reported aims to investigate on the impact of road projections for departing indication in parking lots. Based on field tests, results of the study are rather positive regarding the use and impact of road projections for this use-case.



First, it is shown that the projected signal is better detected than reverse lights, also combined with a longer detection range for pedestrians and cyclists. Furthermore, special comfort is achieved for these latter ones: together with a good detection of the signal, their safety feeling at the sight of the projected signal is quite positive.

For drivers, the safety feeling is still positive in average but lower than for pedestrians and cyclists because the signal is perceived too late: this is mainly due to the speed of movement, which does not let them enough time to react at the sight of the signal but it may also be linked to the fact that they do not perceive their environment in the same way than pedestrians and cyclists.

Second, it is shown that fairly good understanding of the light projection is achieved, although it was a first usage. If both detection and understanding steps are considered, it is shown that 56% of the users became aware of the departing intention thanks to the signal compared to 32 % with reverse lights and that the projected signal hence enhances awareness of the backing situation. As for safety impact, it is shown that the projected signal is not perceived as dangerous and does not provoke a non-disproportionate or non-insecure response. Furthermore, since the projected signal enhances the awareness of possible dangerousness of the situation, it hence significantly increases the number of safe behaviours, such as stop, slowdown and bypass, especially for cyclists.

Also, it is shown in this study that adoption of safe behaviours is significantly linked to good understanding of the signal. This hence emphasises the importance of designing intuitive road projections for better safety impact (shape, colour, close position to the car...). Finally, it should be highlighted that the study was conducted in the acceptance phase and, also, in the particular context of single-lane traffic. This work should hence be continued by studying the appropriation phase and by diversifying the use-cases and parameters.

Success of Driver Assistance through Light Projections on the Road

M. Budanow, C. Neumann (KIT)

The authors presented research done in a comprehensive subject study, which dealt with the possibility of



communicating with the driver via projections on the road.

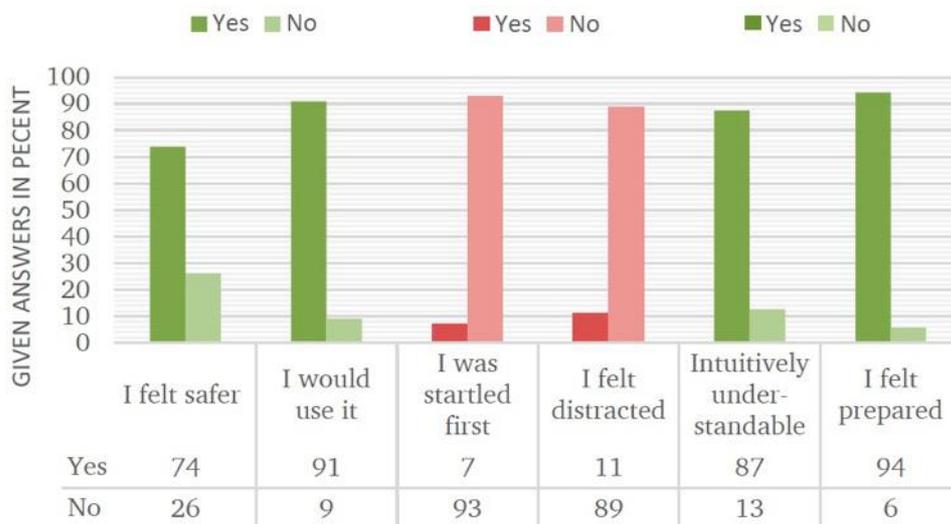
Results show the benefits of projections on the road as an additional driver assistance system. Test persons mastered a construction zone with more confidence and reacted earlier to upcoming potentially dangerous situations with additional projections in their light distribution.

In summary, the study shows that additional, simple projections assist the driver in challenging situations without further distraction.

Two parallel lines showed the most unambiguous

results concerning potential reaction and interpretation of test subjects. To verify the results gained in a simulator study, a field study was designed.

The results of this work show a huge potential of using projections on the road as assistance systems for car drivers. The tested symbols have an early-warning effect on most of the test subjects of all ages and sex. In this field study we showed, that test subjects knew intuitively how to react and reacted earlier with additional projections than with low beam only. The reaction times with projections were comparable to high beam.



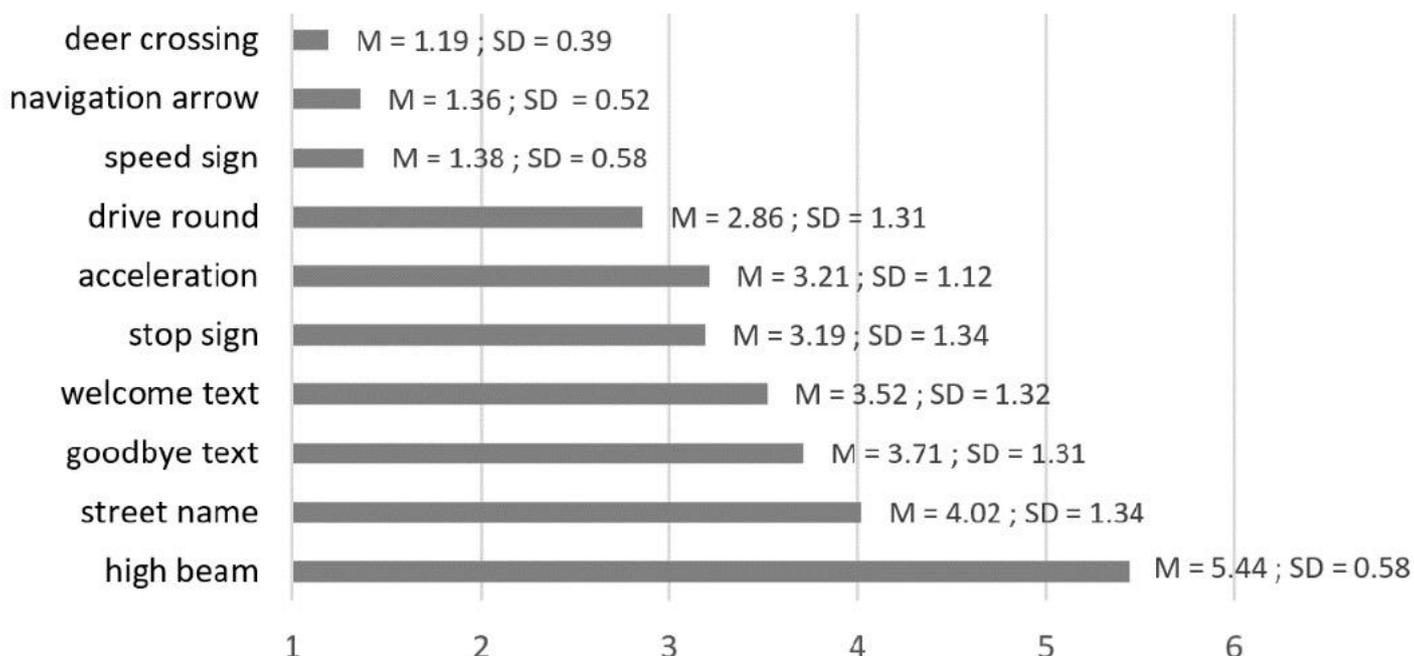
Symbol Projections: Gain or Gadget?

F. Krief, A. Thoma (L-Lab), B. Willeke, B. Kubitz, M. Kaup (Hella)

A large number of high-resolution light projections in different situations were examined within the scope of the studies. The results clearly show that the answer, if symbol projections are a gain or a gadget, is more complex than choosing one side: it depends on the use case.



The primary result within the study is that the usefulness of a light function firstly depends on the interpretability. The best looking, high-resolution symbol projection does not have any safety effect if its meaning is not apparent to the determined person. In some cases, participants had the problem to interpret the meaning of a symbol right or even do not perceive it, because they do not know what to expect of it. The interpretability mostly benefits of a simple symbol shape.



The frequency of the projection plays a big role of the overall meaning on the usefulness as well. In most situations, like for the Optical Lane Assist, the rating gets higher the more careful the moments of the symbol projections were chosen.

Assistants that interact with the environment, like the Optical Lane Assist or the warning for a cyclist, are also well received. It is not only the effect of the comfortable positioning in the field of view, but also the ability to augment the reality in a supportive way.

To improve safety by using symbol projections, it is important to find a language that everyone will understand in the way it is intended

Symbol projections could be a gain if they rated as useful, they increase Increasing the feeling of safety, there is a high acceptance and the projections are intuitive. The big challenge is the lack of standardisation for projection symbols.

Lighting technology developments (especially in LED technology) in recent years and falling cost for miniaturised imagers (DMD, LCoS, and LCD) enable the use of pico-projection systems in automotive applications. The constant demand for new lighting functions which have a lasting impact on the customer experience is the basis for the implementation of vehicle-based pico-projection systems. Furthermore, additional functions can be created which increase safety. This lecture defined requirements for projections around the car. These requirements were used to evaluate the usability of an LCoS based projection system for courtesy functions. Projection systems are already implemented in several BMW and Mini models as shown here.

The requirements that the projections must meet depend on the intended use of the projection. In general, a large number of projection applications from publications and patents can be subdivided into the following classes:

- Design element (dynamic or static)
- Interaction component
- Safety feature
- Road Projection
- Communication between human and machine or between machine and machine

The requirements of these classes can be quite different. Design elements may not require daytime visibility. The resolution, however, has to be quite high if different kinds of symbols, fine lines or writings should be projected. A safety feature should ideally be visible both at night and during the day. Interaction components such as treads for opening a door can be smaller in diameter but should have a quite high illuminance to be seen in different situations.

Small LCoS systems have quite low efficiencies but they are able to provide enough lumens to generate small projections. A sweet-spot balance of illuminance, contrast, and thermal management can be found. The polarising beam splitter has an influence on the efficiency, contrast, and projection colour.

Results: LCoS projection systems cannot meet all the requirements of different scenarios. It is possible to generate dynamic design content near the vehicle with an LCoS-based pico-projection system; the resolution easily meets the requirements. Critical points are to be found in contrast, efficiency, and colour fidelity. Thus, in the future LCoS can be a possible imager for different projections in addition to DMD and μ LEDs. In particular, when RGB laser diodes are qualified for automotive applications, an LCoS system is an interesting candidate as an efficient amplitude modulator and as a phase modulator.

Road Marking Solutions With Pixelized Light Source

B. Reiss, S. Cladé (Valeo)

Benoit Reiss explained in this lecture how a few kilopixels are already offering nice features which improve safety for both drivers and other road users, and how this kind of architecture is also compatible with ADB, using similar monolithic light source as well, making then an optimised global system

For many decades, front lighting functions in the automotive industry was just about low beam and high beam. Just recently, the introduction of glare-free high beam allowed an increased visibility for most driving conditions.



Until now, most of road marking functions have been demonstrated with projection units using hundred thousands of pixel, like DMD or LCD technologies, and discreet pixelised light source. Now it is possible to achieve with much more affordable solution, composed of only a few

thousands of Pixels.

- Functions which are directly addressed to the driver in "normal" driving conditions, meaning driving conditions that do not include emergency situations, like road path/lane marking, road sign projection, and navigation display. Then there are safety alert functions require a high reaction speed from the complete system.

Examples include pedestrian illumination, obstacle highlighting / no-go zone, safety distance projection.

Welcome scenarios are seen just to show to people that the lighting system has many functionalities with its high definition lighting unit.

Among different solutions (matrix of micro-mirror, LCD screen, scanning system and high density matrix of LED), the high density matrix of LEDs, also called Monolithic technology, is the one being the most efficient when



combining the different use-cases since it is a pure additive system.

One technical drawback of such a system is obviously the resolution of the projected images, especially when DLP technology and its 1.2 megapixels. In fact, what is important in such a projection system is the quality of the image on the road. Besides the source itself, the quality

of this image is limited also by the the optical system, which has to correct from optical aberrations, as well as the road surface and other environmental effects.

In case of a HD lighting system, the Valeo solution consists in having a specific electronic module interface, for Picture Control Module. In fact, this module and its associated software are directly creating the image so that the rendering fits perfectly with the driver's needs.

The developed system is flexible enough to require only low adaptations between 1 kilopixel and 1 megapixel solutions, and to fit with most of OEMs architectures.

Optimized ADB Symbol Projection

W. Gonçalves, A. Issoufou (PSA), U. Becherer (Opel)

Whilk Gonçalves proposes the usage of a reduced and optimised set of simple pictograms, easily recognizable to bring additional but not redundant information to the driver. The usage of anti-aliasing techniques enabled to treat images and pictograms for being projected at lower and medium resolution on the road in the context of ADB head lighting with an acceptable quality rendering.

For segments used for guiding and construction, arrows and simple shapes can be represented at an acceptable resolution with less than 10 kilopixels. Recently, HD-LED modules opened the way to new communication possibilities, besides the scope of traditional low and high beam, enabling the projection of symbols and pictograms on the road. Despite the temptation of displaying a big and varied number of pictograms and information on the road, we are facing the saturation and visual pollution it could bring about, with difficult information recognition, if we also consider other displays already available in the cockpit (HUD displays, standard displays, etc.).

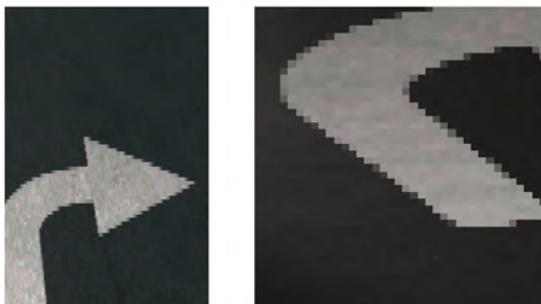
Concerning the symbols to be projected on the road, we have seen many examples in recent works, where a rich



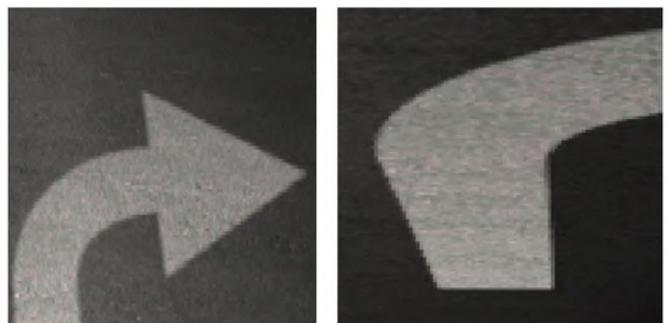
variety of drawings can be in principle used, placed at different locations in the driver's field of view, distance. However, when dealing with this kind of communication, a first question is to better understand what is the perception from the driver's point of view, who will be subjected not only to the graphical information available from the headlamps and other accessory lamps, but

also from the traditional displays inside the cockpit, including the head-up displays (HUD) and other augmented reality displays.

In PSA first approach, simple shapes are interesting as construction lines, selection arrows, segments, some simple drawings. Via a mathematical treatment of the image, we can obtain smooth and acceptable projection of icons even at relatively lower resolution.



We can see the low resolution effect on the projection of an arrow on the road. The staircase-like pixilation can eventually be seen or not depending on the projection distance and the level of details in the image, the state of the road, its reflectivity, etc. To reduce this pixilation



effect, we have used anti-aliasing methods to reduce noise by adding some blurring effects at the image outer. We can see the result from the anti-aliasing filtering. Both set of images were projected using the same resolution. From the driver's perspective, with a much lower resolution than initially expected, we could obtain an acceptable smooth image.

Regulations, Rating Systems and Simulation

Regulation, Innovation and GTB – 67 Years and Counting

Introductory Speech by Geoff Draper, GTB President

Geoff Draper opened his speech by emphasising that our lighting community has something to shout about because lighting Innovation is delivering acknowledged improvements in traffic safety. The UN global regulatory system has contributed to these safety improvements over the past 67 years, strongly supported by GTB.

As the pace of innovation shows no sign of slowing it is clear that good regulation at a global level is required to facilitate its timely exploitation. Changes to the regulatory systems are underway with emphasis upon the development of performance-based technical requirements, so what will the future bring?

Before looking into the future, Geoff summarised the main developments to the global regulatory system that, since the end of the second world war, has slowly but surely evolved to keep pace with innovation. The story started in 1948 when the UNECE Inland Transport Committee was established and this led to the launch of its ad-hoc Working Group on the prevention of road accidents in 1950. GTB started to develop the UN lighting and

signalling regulations in 1952 as an expert group at WP.29.

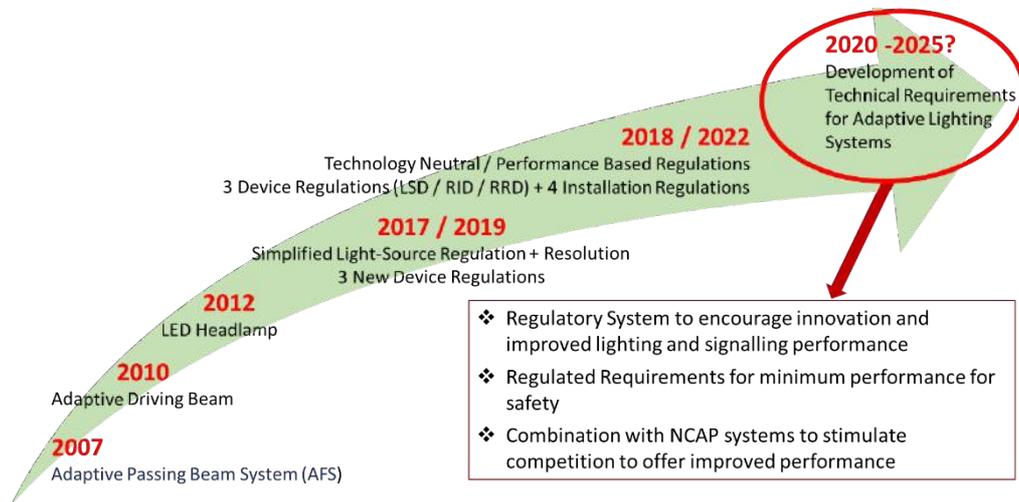
GTB submitted its draft regulations directly to the UNECE Working Party on Construction of Vehicles (WP.29) until 1977 when WP.29 launched its Working Party on Lighting and Light-Signalling (GRE).



GTB continued to be a major contributor to GRE as an expert group working in coöperation with government representatives and other NGO's such as OICA, CLEPA, IMMA etc.

Over six decades the work continued and during that time 41 lighting and signalling regulations were in force, operating under the UN 1958 agreement with 53 contracting parties (national governments), In addition to the contracting parties most nations base their national regulations upon the UN technical requirements, with the exception of the USA.

In 2012 the European Union and Japan, supported by GTB, initiated an activity to simplify the UN lighting and signalling regulations to reduce the administrative burden associated with the introduction of regular amendments to keep pace with innovation. It was clear that without this work it would be very difficult to avoid barriers to the implementation of the new technologies on the horizon, such as LED light sources and adaptive systems.



In 2014, a two-stage programme was launched to condense the text of the 41 regulations into 14 live regulations. The first stage was editorial and was not intended to change the requirements; the result will enter into force in November 2019. The stage 2 was launched in

2018, with the overarching objective to update and harmonise the technical requirements, for lighting and light-signalling, to be suitable for global implementation under the 1958 and 1998 Agreements. The aim is to update the regulations to become technology neutral, with performance-based and objective test requirements, taking into account glare and visibility. This approach provides the opportunity to produce technical requirements, that will be stable and innovation friendly, for the foreseeable future

Reviewing the technological progress since 2007, when AFS was launched, Geoff explained the trend from device to system based regulation and suggested that it is time to start the development of new global regulation for the technical requirements with objective testing of adaptive systems to represent "real world operating conditions"

Complete the simplification of the UN Regulations	<i>Currently on course for completion in 2022</i>
China is simplifying the GB Standards in line with the UN technical requirements	<i>Ongoing Synchronisation is an issue due to 5 year time-lag to amend the GB standards</i>
USA FMVSS108 is "out of step" with innovation	<i>This is a major obstacle to global harmonisation</i>
New developments, e.g. Digital lighting for projection of driver assistance features onto the road surface	<i>How to convince regulators that there is no safety disbenefit?</i>
Comfort lighting around the vehicle – How to Regulate?	
New opportunities for vehicle design freedom (e.g. "long /thin headlamps –new signal lighting arrangements)	<i>Need careful assessment of the impact of high luminance to vulnerable road users</i>
Light signals for autonomous vehicles	<i>Following a GTB proposal WP.29 and WP.1 are working to decide whether such signals are required.</i>
Lighting for sensors	<i>GTB has created a taskforce to study the requirements</i>

The importance of updating the regulations has required enormous effort over the past five years. This cannot be over-estimated, and the result has confirmed that the UN regulatory system has the flexibility and democratic processes to

ensure that regulation does not become a barrier to innovation. The challenge now is to gain acceptance of all stakeholders to seriously work on Global Harmonisation, particularly for the new adaptive system technologies. The major emphasis is upon the introduction of the adaptive systems because they offer real safety benefits for night-time driving. However other technologies such as lighting to aid the sensors of autonomous vehicles, signals for AV's in a mixed traffic situation, the new technologies capable of projecting images onto the road for driver assistance, shall also be taken into the overall project.

The future challenges will be associated with the global regulation of adaptive systems incorporating vehicle level laboratory testing procedures to establish a minimum level of safety. To encourage continual improvement this regulation should be complemented by NCAP systems to encourage competition. GTB is ready to work with all stakeholders under the UN regulatory framework; the process led by WP29 and GRE is the only way to achieve a global solution.

The full version of the presentation that accompanied Geoff's keynote speech is freely available without password on the GTB website at www.gtb-lighting.org.

Ideas for Including AFS and ADB Functionalities Into the TC 4-45 Assessment System

G. Langhammer (Automotive Lighting)

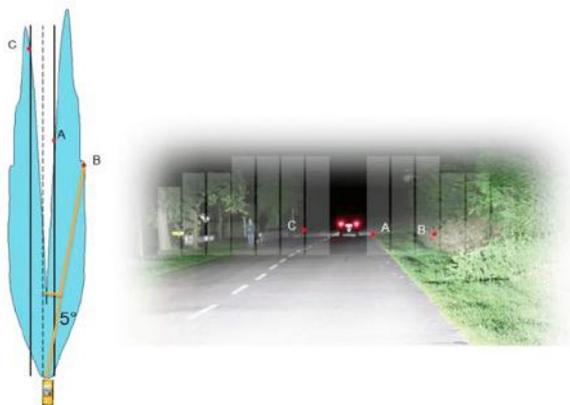


Figure 2: Criteria for assessment of ADB

- Zone A' - range assessment straight road
- Zone B - range assessment curved road
- Zone C' - range assessment pedestrian visibility
- Total Luminous Flux - peripheral information on the optical efficiency of the system

Rating systems are everywhere in our daily life, for instance for the choice of hotels with Tripadvisor or for the choice of cars with NCAP. It is established that more than 90% of buyers are using such rating systems for information and more than 74% have their decision influenced by such written reviews or reports, the rating being even higher for young people.

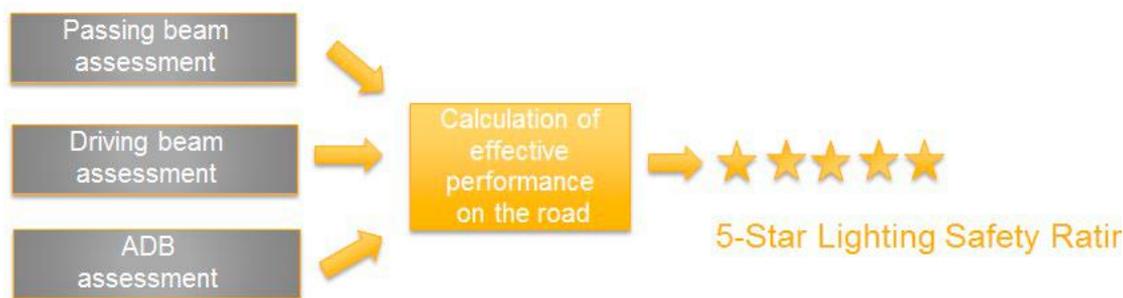
Ratings are also important for lighting systems and till now, the different international organisations have only developed methods for low beam and high beam and so an assessment for the new functionalities of AFS and ADB is lacking.

The new proposed method for these systems is

based on CIE S 021/E:2011 known as TC4-45 assessment system that is using laboratory measurements of headlights under controlled conditions for range, width, flux and glare. This new proposed rating for AFS-ADB is due to the clear improvement of safety permitted by these new devices that needs to be rated compared to normal headlights. For that rating, we targeted a simple to understand rating like the most known of them, reproducible, with results being obtained with reasonable efforts using standard equipment and reusing the already existing

assessments for low beam and high beam while adding a complementary one for ADB.

For ADB, the dynamic mode is not easy to evaluate and so the choice

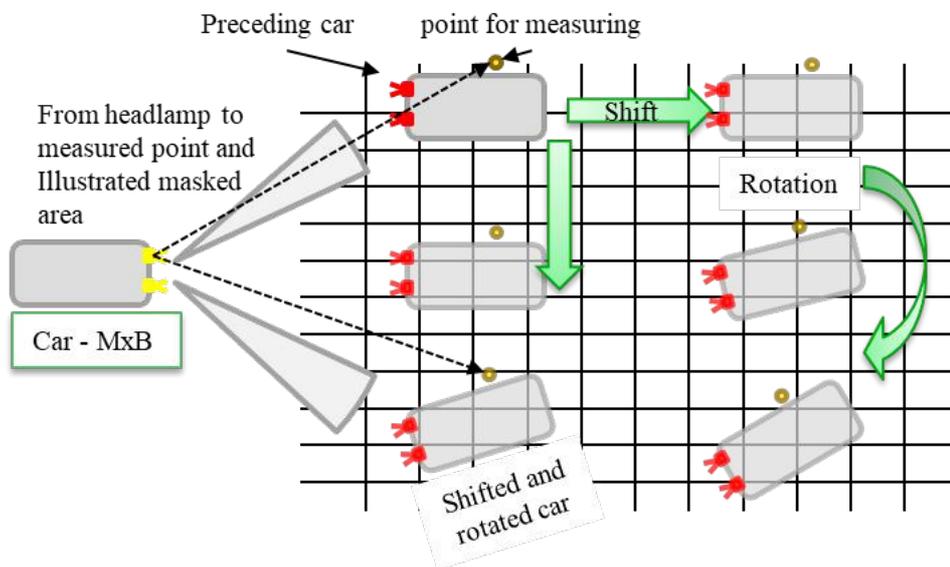


is to use a static method considering the traffic situations defined in UNICE 123, limited however to the distance of 100 m. A similar evaluation is done for oncoming traffic. Thanks to this rating method, seven AFS and ADB systems were analysed, with the calculation of an average and a standard deviation of range for the three different zones considered and similarly for the flux for oncoming or preceding traffic.

Points are after attributed, 1 point if the relevant value is higher than the average value less the standard deviation, 2 points if the value is higher than the average value plus the standard deviation.

With this method, a score of 5 is attributed to Matrix 1,3Mpixels, and a score of 2 for Matrix 7 segments.

A calculation is also done for low beam and high beam with the same method, and an unique global score is defined for each headlamps taking into account these previous scores weighted by the percentage factor of use of each function.



A proposal for ADB systems gets evaluated with a virtual night drive laboratory, the adaptive systems functionalities being performed thanks to the implementation of the software in the loop.

IES files representing the simulated or the measured values of the beam are introduced into the simulator, and a virtual camera is used to define the position of other road users. A static

visualisation as well as a dynamic one can be realised in the simulator.

For a subjective evaluation, a combination of matrix beam implementation and the VND simulator with half-cylinder projection screen illuminated by three projectors are used. This is allowing to evaluate inhomogeneities on road illumination during driving particularly as the light pattern is dynamically changed.

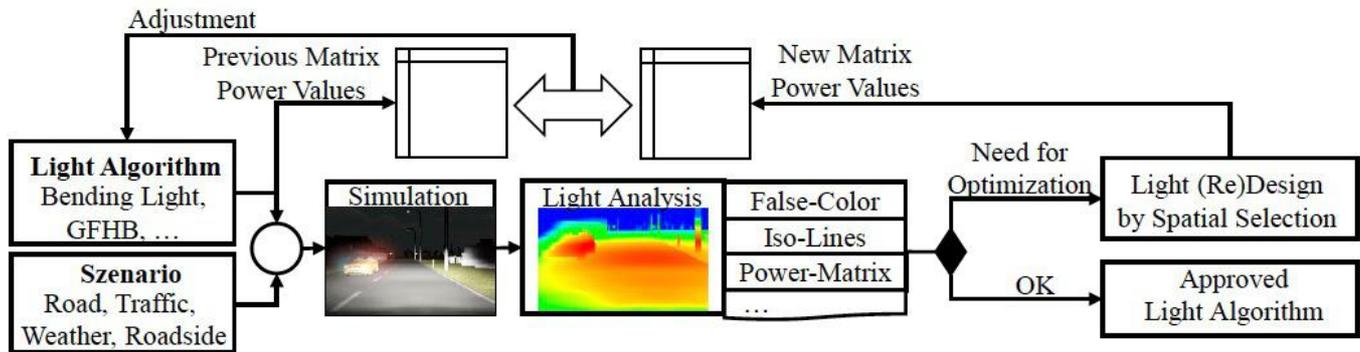
The system is allowing to take into account thousands of situations while simulation time is only in minutes. The system is so suitable for comparisons. The positions of opposite virtual cars are important to evaluate the Matrix Beam performance. The angular position of these cars can also be changed helping to evaluate more closely the levels of glare.

The typical use of the method is the comparison of two or more different optical MxB systems, first with comparison of glaring, and after comparison of the masked areas. The system is flexible, but there is however a limitation due to the fact that the real embedded software and hardware are not used, so the combination of time lags of real time systems are not taken into account.

Naturally, the evaluation corresponding to UN Regulation 123 can also be realised, this being a particularly case of the more general method allowed by the virtual simulator.

Simulation-Based Lighting Function Development of High-Definition Headlamps
N. Rüdtenklau, P. Biemelt, S. Henning, S. Gausemeier, A. Trächtler, (Paderborn University)

High definition systems are much more flexible and consequently more complex than simple matrix beam. Their development as their validation are requiring a simulation tool as the variation possibilities of the representable light distributions are unmanageable due to the large number or individual light sources and their

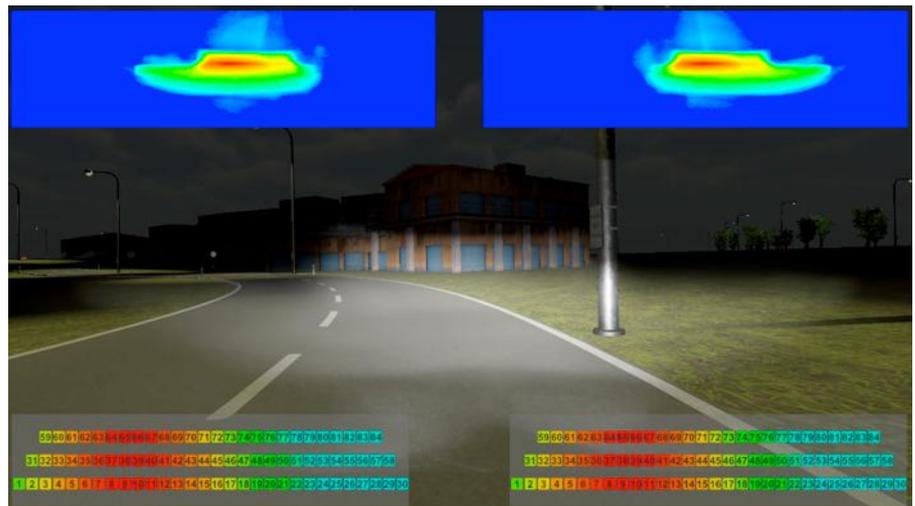


continuous dimmability.

A first simulation was developed in 2018 for HD with 84 LEDs for the light distributions of all LEDs, the control unit receiving information about the conditions of the simulated vehicle and the environmental situation from virtual sensors that served as inputs for the light control algorithms.

Now, a complete methodology using this first base is developed with not only the underlying headlamp system, but also the route, the weather conditions and the traffic behaviour.

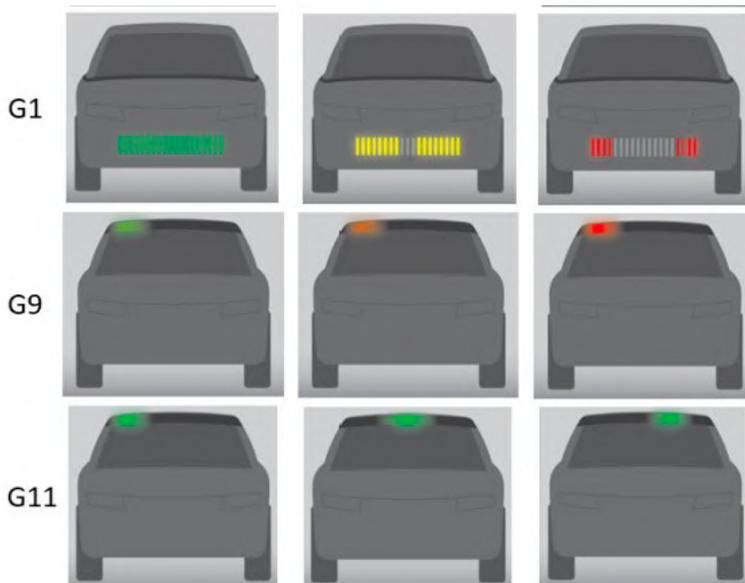
The light is then analysed with a real-time false colour visualisation of the matrix current values and the resulting intensity distribution per headlamp. A complementary work is targeted for real-time on the PC. A solution could be to use AI (Artificial Intelligence) to produce learning data on the PC, and to train neural network to map sensor input to power values.



LightCom—Autonomous Vehicle's Communication with Pedestrians

N Jezeršek (Hella Saturnus), Dr. B. Bajec, Dr. J. Klemenc (University of Ljubljana), J. Miklavc (Studio Miklavc)

After analysis of previous studies and with the team's own ideas, several concepts of messages from AV to



Pedestrians were defined. These messages are from different types: Projections, Communication screen, LED communication strip and Audio signals. The choice is done upon criteria of universality, time independency and simplicity.

A survey with 233 participants selected the best signals, but some were rejected by the team for instance the projection messages as they cannot be seen during daytime. The same practice was used for the selection of the audio signal. Thanks to this selection, a practical demonstrator was built with three independent,

individually controlled LED strips with a sound generator. The light output was not powerful enough during the day and so experiments were realised in the evening. For safety reasons, only the message "It is safe to cross" was transmitted.

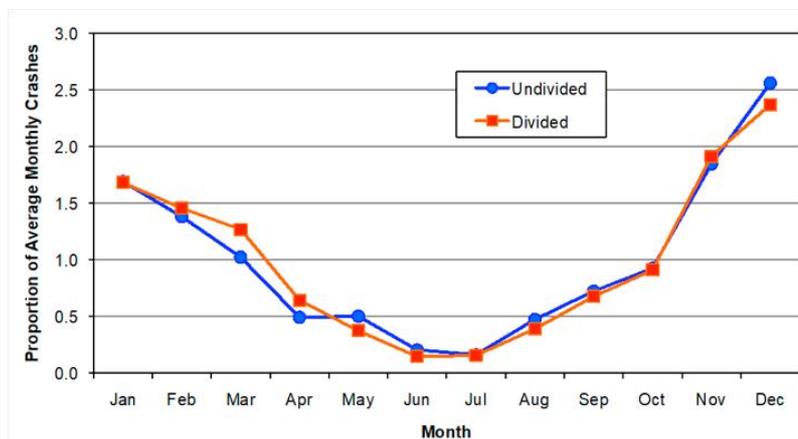
Another survey was done with the pedestrians met during the test with the following results for the understanding of pedestrians:

- Safe pedestrians crossing: 29%
- Human detector: 13%
- Car is signalling: 13%
- Special vehicle type: 13%
- Car attracts attention: 16%
- Other: 16%



Quantifying the Safety Effects of Headlamp Glare Using Crash Data M. J. Flanagan, J. M. Sullivan (UMTRI)

Tradeoffs between seeing and glare are central to the design, implementation, regulation, and rating of headlighting systems. The researchers state that headlamp glare can affect driver vision, which gives rise to the reasonable expectation that headlamp glare can affect nighttime traffic safety. The effect of glare on crash risk has long been unquantified, though, making it effectively impossible to base regulatory, rating, and system performance decisions on objective crash risk factors. This lecture describes the researchers' scrutiny of lane separation and the presence of medians or median barriers as an entry point to estimating glare effects on crash likelihood. A previous study by these researchers found that if glare does increase crash risk, the increase is too small to be detected by the methods used. This new study built on the previous study by adding information about changes in pedestrian activity throughout the year—and, again, found no detectable effect of glare on crash risk. The authors point out that their result doesn't necessarily mean glare does not affect crash risk, but rather suggests such an effect is small relative to the change in risk caused by ambient-light changes throughout the year.



It is known that low beams don't provide adequate seeing distance for the speeds drivers actually go at night; this seeing side of the equation has been quantified. But the glare side of the equation is much more difficult to quantify, not least because glare contributions to a crash are generally not considered or tabulated by investigators, and it would be very difficult or impossible for them to do so. The researchers state that a relevant factor that is available in crash data is the

configuration of the roadway with respect to the opposite-direction lanes, and these configurations probably correlate with glare exposure. A road with one lane each direction and no median or barrier would presumably expose drivers to maximum glare levels, while a divided highway with opposing lanes separated by a median strip or barrier will presumably reduce the glare drivers are exposed to.

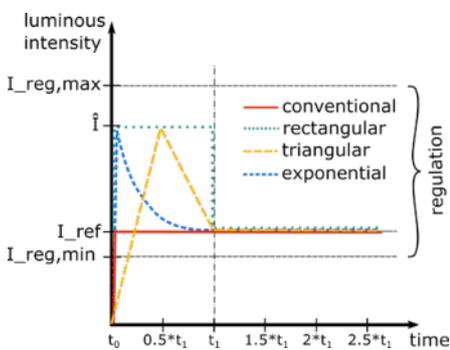
The researchers consulted estimates of the variance of travel activity with time of year and time of day, including variances with changes in weather and ambient light. Pedestrian crashes were plotted proportionally by month, so as to illuminate the effect of ambient light on crash risk. The researchers posited that a glare effect on crash risk would increase the range between low bright summer and high dark winter crash rates for undivided/high-glare roadways than for divided low-glare roadways. No significant difference in that range was found, which the researchers interpret as an indication that any glare effect isn't strong enough to be detected by this method, and/or that the effect of headlight glare on crash risk is small relative to the crash risk effect of seasonal changes in ambient light. The experimenters do acknowledge that glare is known to impair driver vision in experimental studies, which tends to weigh against a null effect of glare on crash risk, and suggest that more sensitive methods are needed for analysing crash data for glare effects.

DVN Comment: This is a notoriously difficult problem, how to quantify the effect of glare on traffic safety. This result might be frustrating in terms of hope for a method of doing so, but there is great scientific value in reporting it. There is, of course, the risk that adherents to the American philosophy of dismissing glare as a safety hazard might see this study as "proving" them right, while adherents to the European philosophy of minimising glare even at the expense of visibility might further dismiss American research on the subject.

This lecture described research aimed at optimising the stop light function for maximum attention-getting power (i.e., fastest reaction time) with minimum glare. The variable-intensity provisions have led some automakers to provide nighttime stop lights near the minimum allowable intensity. But higher stop light intensities give faster reaction times and higher attention levels.

So, the researchers set out to investigate optimised stop lamps that provide high intensity at first (for strong attention-grabbing effect and shortest reaction time), then dim down to near the minimum allowable intensity to avoid glare to drivers who might have to look at the stop lights for prolonged periods, for example in stop-and-go traffic or at long traffic lights. Early research showed equal discomfort glare ratings for this kind of bright-pulse-then-dim stop lamp as for constant-low-intensity stop lamps.

The researchers note that only during the first few hundred milliseconds of stop light activation can possibly affect reaction time, but the longer-term stop light operation is what gives rise to discomfort glare. So they set out to try stop lights that provide the highest luminous intensity for the first 200 milliseconds of activation, then provide lower intensity for prolonged operation. Aside from the baseline condition (in which the stop lamp always provides about 80 cd), there was a rectangular pulse (stop lamp provides high intensity from 0 to 200 ms, then immediately drops down to the baseline intensity), a triangular pulse (stop lamp ramps up linearly to the high intensity, then linearly down to the baseline intensity); and an exponential pulse (stop lamp rises immediately to the high intensity, then exponentially fades down to the baseline intensity). The researchers note that the exponential pulse could minimise discomfort glare because of its earliest dimdown, while maintaining the shorter reaction time benefit and also making the dimdown effectively imperceptible to the observer—this in comparison to the more conspicuous intensity stepdown of the other pulse shapes.



The experimenters noted the constraint of UN Regulations that generally require light of substantially unchanging intensity during operation, but an exception is to be found in the allowance for turn signals to provide sequential activation, a condition of which is that the signal must be fully lit within 200 milliseconds of onset. So, the experimenters used intensity pulses that reached their final (low/baseline) intensity at 200 ms. All test subjects viewed all the different pulse presentations straight-on and at an angle to simulate realistic traffic situations. Only with constant intensity changes were glare perception changes found; the high-intensity pulses did not increase perceived glare.

As to reaction time, it did not significantly vary across all stimuli presented—a contradiction of previous studies. Nevertheless, the researchers assert strong indications in the measured data that the pulse shape might influence reaction time and provide a means of optimising the stop light signal. They suggest further research should figure out conditions wherein more intense stop lights reduce reaction times—those are the conditions under which they think a bright-pulse/steady-sustain stop light signal might provide significant benefit.

Integration of a Melanopic Light Unit Into a Passenger Car—Initial Results From a Field Study
S. Schüler, D. Betz (Daimler) , R. Popp (University of Regensburg)

"Human-centric lighting" (HCL) is a popular topic of discussion amongst scientists and lighting technologists. One intersection of HCL with driver performance is the chronobiological, psychological, and physiological effects of light on people. The basic idea is that different light quality (depending on the time of day and the spectral content) can exert a stimulating or calming effect. Daimler have been working on what they call "Daylight+", first with truck drivers—a 2017 study in Finland suggested significantly positive effects, which led Daimler to do a bigger study in passenger cars equipped with a melanopically active light. This lecture presented the results of that bigger passenger car study.



40 test drivers experienced and rated the "Daylight+" melanopically active light over a total of 20,000 kilometres. Tests were carried out for technical parameters (light measurement, vehicle driving data, etc), as well as psychological and physiological factors—reaction tests, questionnaires, EEGs, and so on.

The research hypothesis was "With the use of melanopically active light, a commuter car driver will remain well-performing, attentive, and alert by day inside the vehicle". A second goal was to check whether the special light exerts a positive effect both in the morning and in the afternoon, and

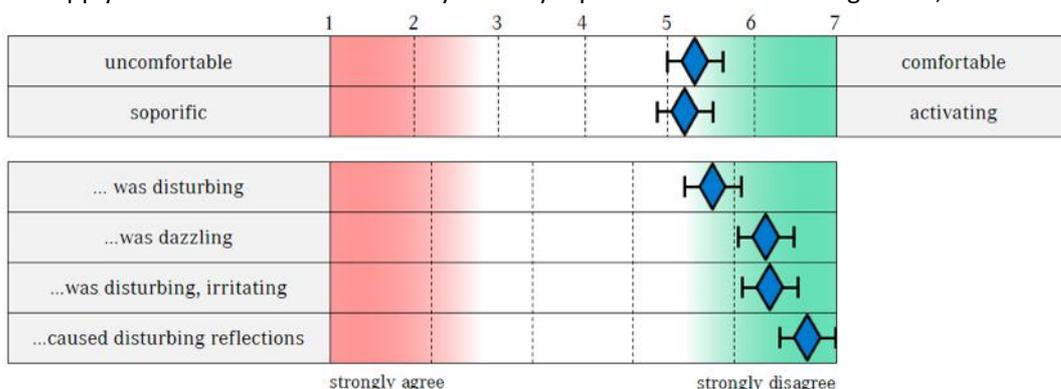
whether the time of day affects the degree of effect.

In contrast to the initial truck driver study in low-light Finnish conditions, the present study was done in southern Germany with higher ambient light levels. Nevertheless, the data collection was done during morning and afternoon drive time half-light conditions. Another difference to the first study was that the driving times were around two hours, shorter than the truck drivers' routes. The car drivers' routes were deliberately chosen to be well known, so a monotonous condition would be quickly achieved. In order to facilitate this monotony and countervail the arousal that can accompany a special test situation versus a routine commute, test subjects were speed-limited and forbidden to listen to the radio or use their phones.

Test subjects didn't just hop in the car and drive off; they were first given a "light shower" with the special light operated at full intensity and with a high blue component. Then began the test drive, with the special light's intensity dynamically adapted in accord with the ambient brightness. Practically this equates to a five- to sixfold increase in the light dose at the driver's eyes.

The special light was shown to apply illuminance at the driver's eye closely equivalent to ambient brightness, which the researchers assert

means the "Daylight+" unit can offset darkness inside the vehicle and artificially restore natural daylight conditions. Questionnaire responses indicate that drivers found the special lamp



"activating" and "comfortable". They found it undisturbing, not dazzling or distracting. EEG results show that drivers were objectively more alert with the "Daylight+" lamp than without it.

Boosting Human Performance: Human Subject Research on Energizing Effects by Overhead Light Panels for Interior Lighting

A. Niemeyer (Audi); C. Neumann (Light Technology Institute Karlsruhe)

Like the Daimler lecture, this presentation looked at the idea of optimising drivers' wellbeing and performance by means of a biologically-active light. The basic root of the idea is that light is known, in increasingly detailed ways, to have non-visual effects: it can affect mood, vigilance, concentration, and circadian rhythm. So, can these

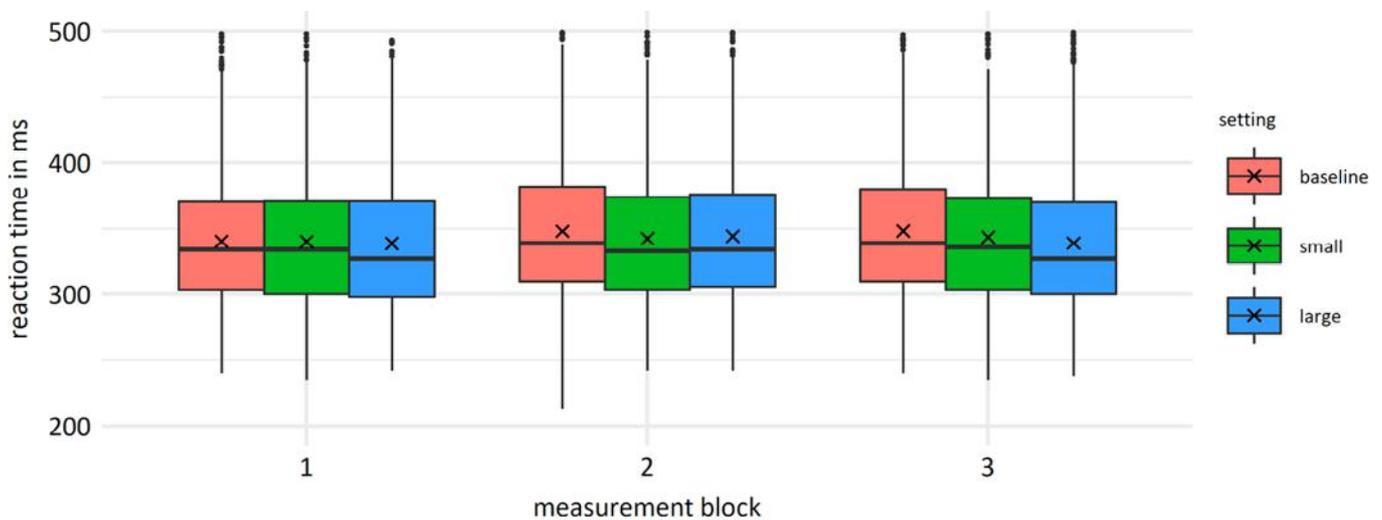


effects be harnessed by dint of lighting inside the car to improve vehicle occupants' attention and focus? The researchers start by noting that the effects of light properties like colour temperature and illuminance are relatively well known. What they wanted to look at was the perceived size of the light source—a question important not only in terms of the effectiveness of the new light, but also in practical terms of integration into the car.

The research described in this lecture involved a laboratory study in which test subjects were exposed to three scenarios: a baseline (dim background light only), and two test scenarios with overhead light panels of two different sizes, but producing the same illuminance. In the baseline scenario, driver-eye illuminance level was 11 lux. For the test scenarios, it was 200 lux. The two panels were 145 × 190 mm and 400 × 560 mm.

Under all three scenarios the test subjects did attention and working-memory tests, and there were questionnaires about mood and sleepiness.

Findings: subjects felt up to 14% more alert with both the small and large light panels than in the baseline condition. This manifested as prolonged alertness with the panels, and a tendency to grow sleepy without the panels. There was no significant difference found between the small and large panels' effects.



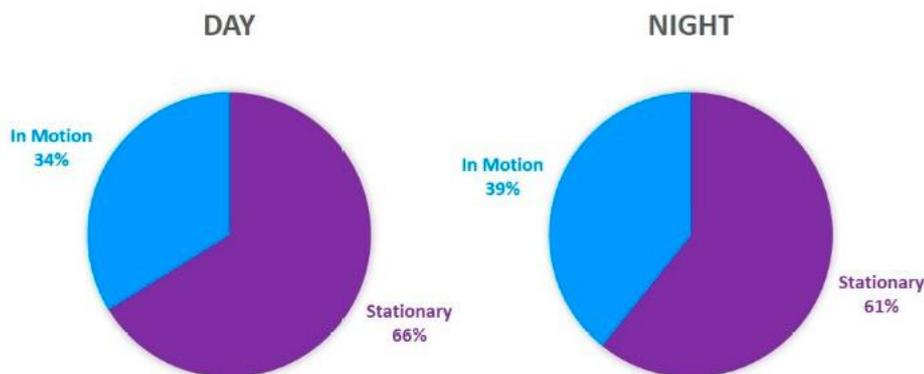
Objectively, no significant effect on reaction time was found for either the small or large light panels versus baseline conditions.

Energy Saving Potential of Headlights by Determining the Current Utilization Rate of Headlight Functions

A. Erkan, K. Kosmas, J. Kobbert, T.Q. Khanh (T-U Darmstadt)

Energy efficiency and CO₂ emission is a central topic of discussion and work in the automotive sector. Headlamps take energy to run, so their power consumption factors into a vehicle's overall energy efficiency and CO₂ production. The headlamps' power consumption becomes even a bigger issue in context of electric vehicles, as every bit of electricity used to run the lights cannot contribute to the vehicle's range. The researchers in this work figured out the real power demands for various functions (low and high beams, daytime running lights, turn signals, etc). This was done by determining the actual usage durations and current draws for the various functions. Vehicle OBD system data was used to obtain the data, which was then processed to arrive at the real utility rate of each light function. With this basic data, the researchers set out to calculate the energy saving potential available for each light function.

The data gathering phase was carried out on two routes, both in rough figure-8 shapes to contain both left- and right-hand turns and curves. One route was about 90 km long and took about two hours to drive; the other was 136 km long and took about 2½ hours. Test drives were done in peak-hour traffic (16:00 to 18:00) and after dark, starting at 22:00. Test subjects controlled the car's lights manually; automatic headlights were not used—thus allowing for scrutiny of whether some light functions might be under- or over-used (it is already known, for example, that high beams aren't used nearly as often as they should be when it's left up to the driver).



The collected data was analysed by reference to prevailing conditions on switch-on (position, speed, etc) so as to determine the amount of time, for example, that the vehicle's stop lights are lit while the vehicle is standing still at a traffic light or in a traffic jam, versus the stop lights being lit to indicate that the vehicle is actually slowing down.

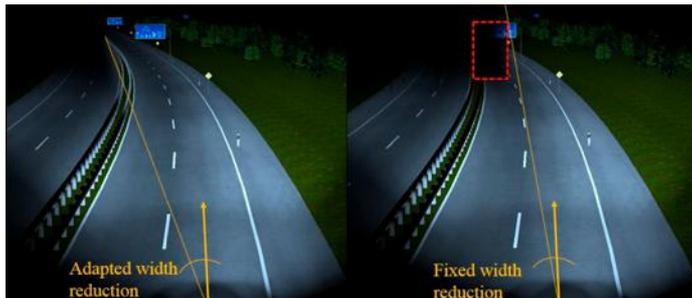
The results show that during the day, the DRL is (naturally) the most-used function, being active nearly 100% of the time. The stop lights come second, at 27.2% of the time. All other functions show negligible usage rates. At night, the low beams and position lights take the № 1 spot (again, nearly 100% of the time) with the stop lights coming in at 15.5% (less than the day figure due to lower traffic density) and the rest of the functions are usually not lit. More detailed analysis shows that the stop lights are lit with the vehicle stationary over 60% of the time, day and night. The authors suggest the intensity of the stop light could be reduced to 50% while the vehicle is stopped (and not signalling an active slowdown), thus saving energy. Calculations show that LED stop lights save over 80% in energy versus incandescent stop lights, and the dimmed-stoplight idea gives perhaps another 5 or 6 percent savings potential. Which sounds maybe not worthwhile, but in CO₂ terms it looks more attractive. Still, the authors note that the resultant CO₂ emissions reduction is scant in relation to the vehicle's overall emissions.

Democratization of Advanced Driving Beam Systems—Good Light for Everyone!

C. Neitzke (Opel)

This lecture starts out by describing Opel's progress in fulfilling their commitment to offering high-tech lighting systems at affordable prices across the whole array of vehicle classes. The presenter emphasised that putting ADB on cars of multiple segments means knowing, in detail, the requirements specific to each car class—the right balance of price and performance.

Opel's strategy, according to the presenter, is that the existing light functions should be progressively improved by continual optimisation. An example is given with the motorway mode of a glare-free high beam system. This was originally developed to prevent dazzle to oncoming traffic in recognition of the fact that oncoming cars are largely invisible to front cameras, on account of guard rails on motorways.



So, when motorway conditions are detected, motorway mode means the light width is reduced toward oncoming drivers. The degree of width reduction was set as a compromise between avoiding dazzle and retaining the equipped driver's seeing distance on their own side of the road. That becomes a problem in left-hand curves (in RH-traffic countries), as it can either leave the equipped driver short of

seeing distance in the curve (if the width is reduced too much) or expose oncoming drivers to glare (if the width is not reduced enough). Opel worked to use the low beam swivelling algorithm to calculate the optimal beam width restriction angle. This results in both improved forward-leftward seeing distance and reduced glare to oncoming drivers, as shown in the images here.

A similar philosophy is being applied at Opel for many other aspects of lighting system optimisation. One example: tuning the system performance and output characteristics in accord with customer expectations and driving styles that differ across vehicle classes. Tuning parameters can include such things as the sharpness of the edge of the shadow zone, for example. The lecturer wrapped up with a discussion of how Opel is applying ZKW's Pixel-Lite module in new systems.



BEVs Versus ICVs: First Real Time Investigations on Temperature Load Differences in Headlamp Environment M. Manderscheid, M. Hamm, M. Klausner (Audi)

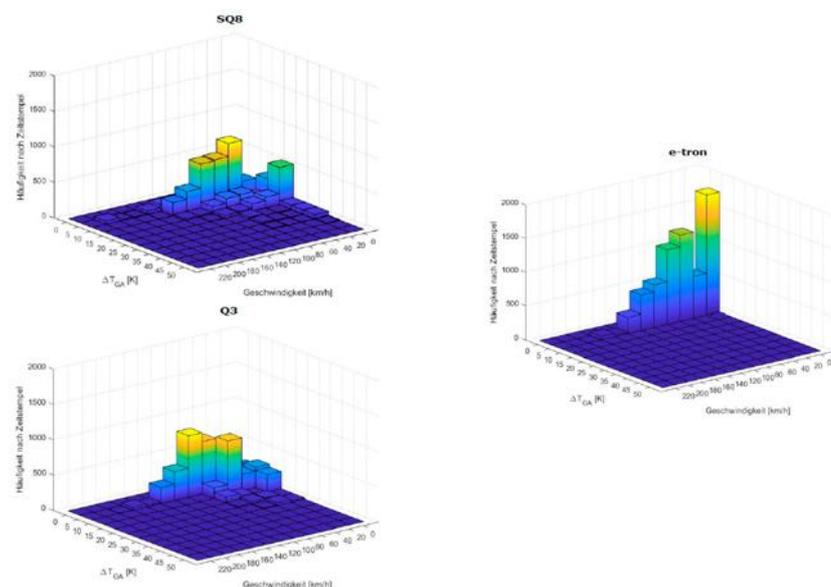
Thermal loading is a central issue in headlamp development. Because of headlamps' location, combustion engines put a lot of heat into them. There's internal heat, too—in the past it was from halogen bulbs and tended to put stress on reflectors, lenses, and other plastic components. Some heat still comes from LEDs, though the main focus of heat management has shifted to keeping the LEDs and electronics within their comfort zone as far as operating temperature goes. The relative narrowness of this zone has led to the use of fans, heat pipes, and other strategies to carry the heat off the LEDs.

The authors of this paper pose the central question of whether and how the accelerating shift toward electric powertrains will affect the thermal loading of headlamps. Although BEV (battery electric vehicles) have markedly different underhood topography, there are still heat emitters that stand to put heat into the headlamps. So, this lecture looked at the headlamp thermodynamic load differences between battery electric and combustion-engine vehicles.

Three areas in Germany were chosen to represent country, mountain, and urban regions. A variety of test drive scenarios was put together to include differing speeds, traffic jam situations, and other aspects of ordinary daily-commute vehicle use. Test vehicles included combustion-engine and battery-electric cars all with matrix beam headlamps. One limitation of the test is that the limited number of test cars meant measurements were taken on different days, which differed in ambient temperature.

The researchers found that the headlamp temperature depends strongly on the vehicle speed. Faster speeds reduce headlamp temperatures, presumably due to rearward airflow past the headlamp. It was not demonstrable that mountain roads drive up headlamp temperatures by dint of higher powertrain load, though they note that road speeds higher than the urban/traffic jam situations might have compensated to some degree for higher

thermal loading due to higher motor or engine workload.



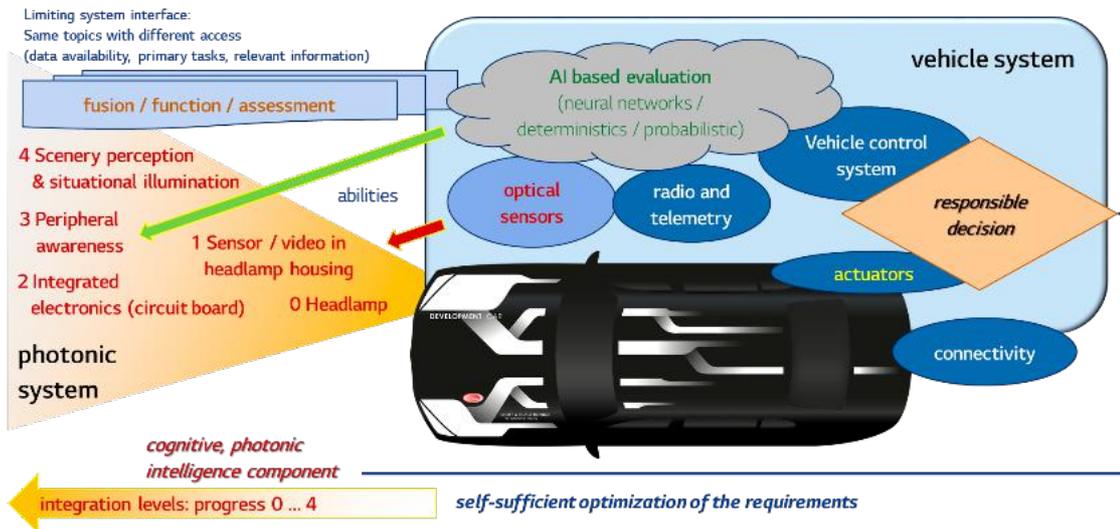
All in all, the experimenters found that there is in fact an advantage to BEVs from the headlamp-thermal-management standpoint: the electric cars put significantly less heat into the headlamps than the combustion-engine cars. It is stated that further research should broaden the range of cars scrutinised in this manner to establish a more granular database.

Integration of Sensors in Headlamps Leading to a Multifunctional Component for Environmental Perception P. Hartmann, S. Weissensteiner (ZKW)

For level 3, 4, and 5 autonomous driving, not only the presence of a full suite of sensors is essential—but also their position and their uninterrupted ability to do their job without impedance by dirt or damage. This argues for putting sensors into the headlamps, where they'll be protected by the cover lens and their outlook maintained by known technologies for keeping headlamp lenses clean. This lecture explains the guiding philosophy and practical work at ZKW toward that goal. The researchers describe their efforts toward broadening notions of lighting functionality to include perception in general (human and machine). Practically, their goals are progressive mechanical and logical integration

of sensors into headlamps, and development of new methods to combine illumination and sensor-scanning technologies and new ways of integrating data from multiple sensors to attain and leverage situational awareness.

Examples of how this move from lighting to perception might include advanced predictive abilities, and the ability to assess the quality of sensory data and then react to optimise perception (as by changing frame rates and exposure times, directing more light to where it's needed for a particular kind of sensory perception, etc) under prevailing conditions of dirt, vibration, glare, stray light, traffic density, weather, etc.



The authors point out that for all of this to work well, the headlamp cover lens must be kept clean, by lens washers and/or various coatings. Assuming that caveat is met, the next one is that physically

widely distributed sensors make it difficult to build recursion and feedback loops except at the software level. They state that hardware integration is prerequisite for the kind of recursive control they seek to realise. This requires a whole-system view of what should best be computed where, which involves tradeoffs: embedded computing capacity within a sensor minimises long-distance data transfer, but increases the weight, size, and internal thermal load of the package. Remote computing, on the other hand, allows for compact sensors of low mass and negligible thermal output, but requires high-bandwidth, error-proof data transfer infrastructure, which increases system cost. Mass, packaging, complexity, and latency all have to be co-optimised.

And driving is the opposite of a static task; it is highly dynamic, and the researchers describe the necessity this creates for predictive control of illumination based on current and past "observations". This, in turn, requires geometric reasoning and semantic understanding of the scenery. With these and other tricky requirements, a key question is whether and how the sensor package can be tuned to a specific scenario automatically, given enough example data and good enough image quality.

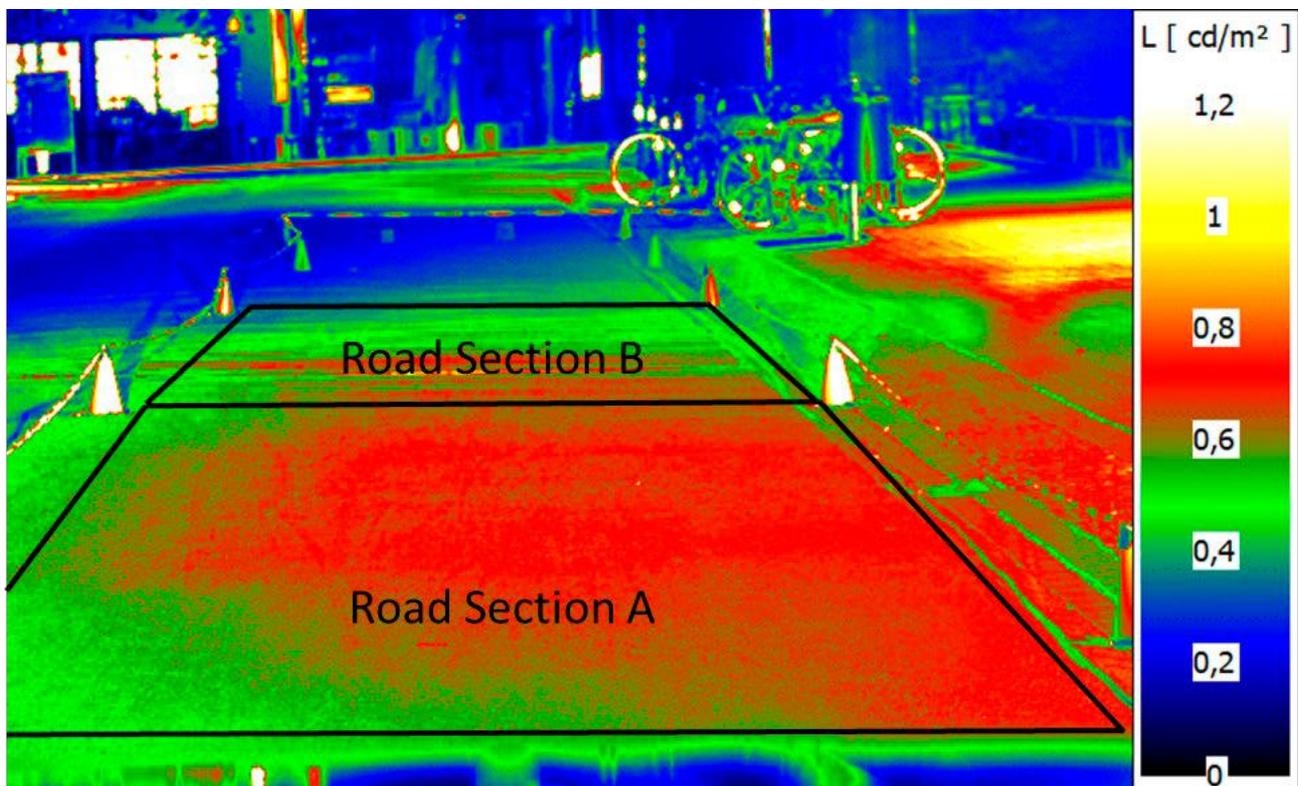
A practical experiment was done with lidar sensors integrated into headlamps in a climatic wind tunnel providing variable rain, wind, and fog conditions. The experimenters found severe damping of the signal due to fog, manageable signal noise during heavy rain, and that the sensor must be calibrated in accord with the curvature of the headlamp lens it is behind. They assert that smart lighting needs relevant information from sensors, and sensory data is significantly improved by smart lighting, so a holistic, cognitive-photonic "sight" approach benefits both sides of the equation.

Reducing Head Lighting Level on Urban Roads for Different Street Lighting Situations

M. Wagner, A. Erkan, K. Kosmas, T.Q. Khanh (TU-Darmstadt)

The research project described in this lecture looked at the effect of street lighting on driver vision when low beam headlamps are in use. Road surface luminance levels from street lights can exceed those from headlamps, especially in the far field—that is, street lighting provides a crucial part of the lighting needed by the driver. This implies that some amount of the headlight performance might be superfluous, so perhaps the headlamps can be safely power-reduced in some cases, to save on increasingly-limited CO₂ emissions.

One question in the research looked at the threshold levels of light reduction at which subjects consider the lighting still adequate for safe driving. A test car's LED headlamps were specially equipped for variable intensity (by dint of PWM) to carry out the experiment. This was done in a variety of streets in Darmstadt. The road area to be evaluated was divided into two sections; one from 10 to 20 metres in front of the car, and the other from 20 to 30 metres ahead. A variety of headlamp intensities was presented in randomised order, and yes (adequate) and no (inadequate) reactions from test subjects were correlated to various headlamp intensity levels. It was found that under some streetlighting conditions, headlamp output can be dimmed by up to 50%, which (for



specified headlamp system parameters) can mean a CO₂ reduction of 0.88 g/km.

The authors assert that their main result is that it is possible headlighting levels can be reduced in some circumstances—not statically, but dynamically, with a variable lighting distribution taking into account the street lighting levels and other factors. They also assert that further research should be done on the 20-to-30-metres-ahead zone, and to contrast sensitivity for objects on the road surface.

It is perhaps a little difficult to accept that headlights can or should be dimmed, given the links between headlight performance and (for example) pedestrian safety. However, the idea is not revolutionary—decades ago broadly similar ideas came forth in the forms of "town lights" and the British "dim-dip" function. What's new and revolutionary is the idea of dynamically linking the headlight intensity adjustment to prevailing streetlighting conditions. There is also the caveat that subjective impressions of lighting adequacy don't necessarily agree with objective lighting needs.

Session: Future of Automotive Lighting

Introductory Speech by Ralf Klädtke (ZKW)

Ralf Klädtke opens the session of *"The future of the automotive lighting"* at ISAL, making a talk on his vision . He starts by automotive evolution: The car of the future is electrified, autonomous, shared, connected and yearly updated, the foreseeable trends suggesting that autonomous and shared mobility will increase greatly by 2030.



Coming to lighting, he presents the "5 S" which summarises the market trend :

Smaller, Safer, Smarter, Sustainable, Style

• **Smaller**

We see the evolution, model after model for every brand.

• **Safer**

Road projections, Animations and pictograms to communicate.

Light-in-motion-effects, exterior displays.

Sensor integration 360° at the 4 strategic corners.

Artificial Intelligence, ECU, SW, Sensor Fusion..

• **Smarter**

High resolution ADB using camera and artificial intelligence.

Expected marketshare of 15% by 2025, growing strongly in all market segments.

High resolution DLP, μ LED, Laser Scanner.

• **Sustainable**

High efficiency and low weight lighting technology optimising vehicle power consumption and range with minimised environmental impact

High efficient reflector module

• **Styling**

Exterior displays and supplemental lamps.

Light-in-motion effects & Animations for individualisation.

To conclude, Ralf presents the market trends :

"Digital" lighting for conventional cars & AV New Communication Functions

Communication Car to Driver/pedestrians

Construction guidance lighting

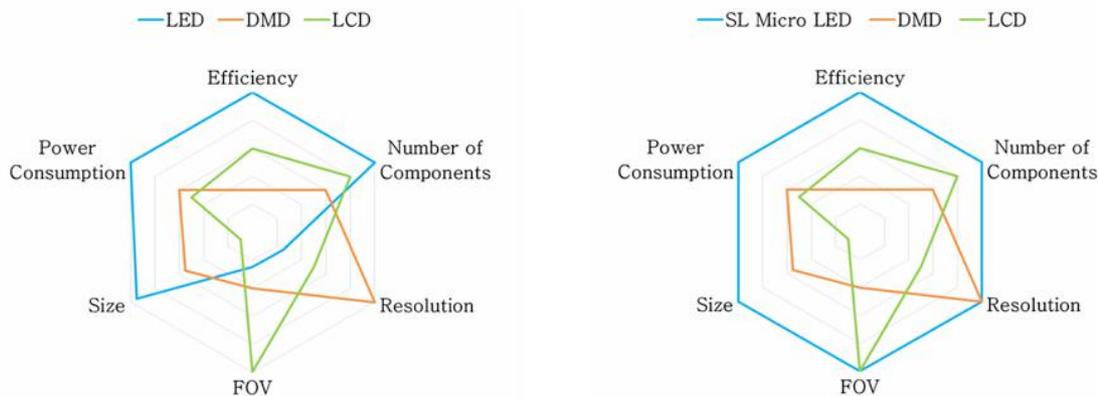
Obstacle avoidance lighting and warning functions

High resolution pixel lamp for future "SL μ LED Good Solution in all criteria"

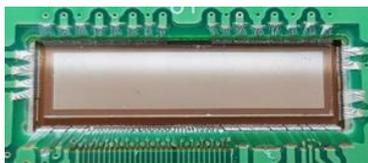
H.- D. Kim, SL Corp

How can we make the best high resolution pixel lamp?

SL Micro LED, named SIMPL by SL Corp, is a good solution in all the defined criteria

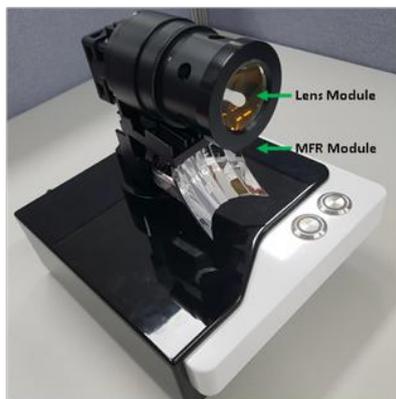


Since the SIMPL has been developed only by taking advantages of LED, LCD, and DMD, it has a number of advantages over other technologies and it can contribute to the greater visibility, safety, and communication.



400x100 pixels with pixel size of 35 μ m

Achievement



Lens Module

Low beam : 300Lm

High beam : 980Lm

FOV (H) : +/-20°

Optical efficiency : 40%

MFR Module

500Lm

FOV (H) : +/-40°

Optical efficiency : 55%

In conclusion,

- The technology can provide a single module which can illuminate wide high beam pattern
- A lot of energy can be saved through a high-efficiency module.
- If the pixel is turned off, it can be more efficient than the subtractive system.
- It has a high contrast ratio (more than 250:1) to make ADB pattern.
- It can make any pattern by digital control.

Revolution Behind the Lights: From Hardware to Software

A. Blondel (Renault)

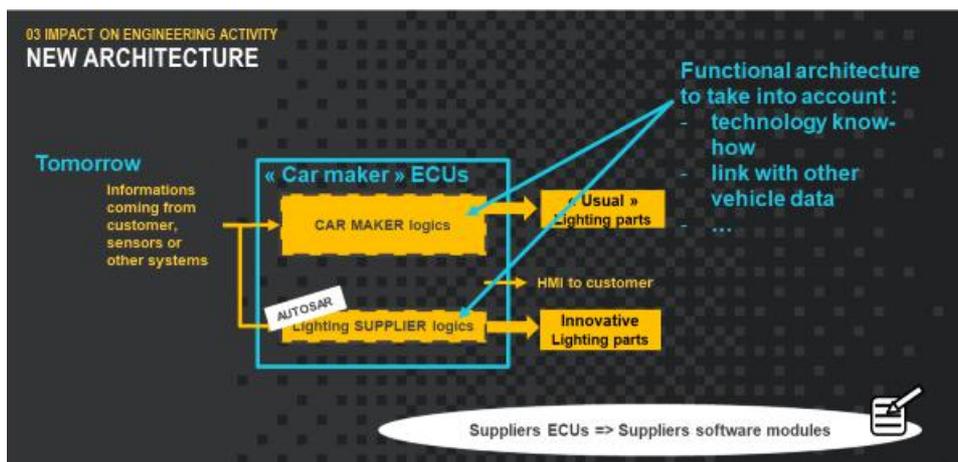
Annie Blondel starts her lecture saying there is more and more content behind headlamp : leveling ECU, lighting ECU, digital ECU, ADAS ECU, with more and more cost and complexity.

We have to change and software is the solution.

We must :

- centralise ECUs : Central logics built a simply architecture and ECU internal data is easier to manage.
- get new skills as OTA, and AUTOSTAR

About manpower, the main solution to reduce it, is Standardisation of ECUs and software modules. Standardisation is key factor to limit manpower on car maker side and supplier side.



From car makers : To delete physical boxes and to integrate software modules

From lighting suppliers : To provide software modules instead of additional ECUs and to provide lighting parts able to communicate through standard interfaces (HW, protocol and content)

Future Automotive Lighting: Way to a Simplified, Automatic, Controlled Light Philosophy Dr. R. Neumann (Varroc)

Trends with increased traffic in megacities and needs for efficient low power solutions with optimised safety will lead to a simple, reliable and fully automatic controlled lighting system.

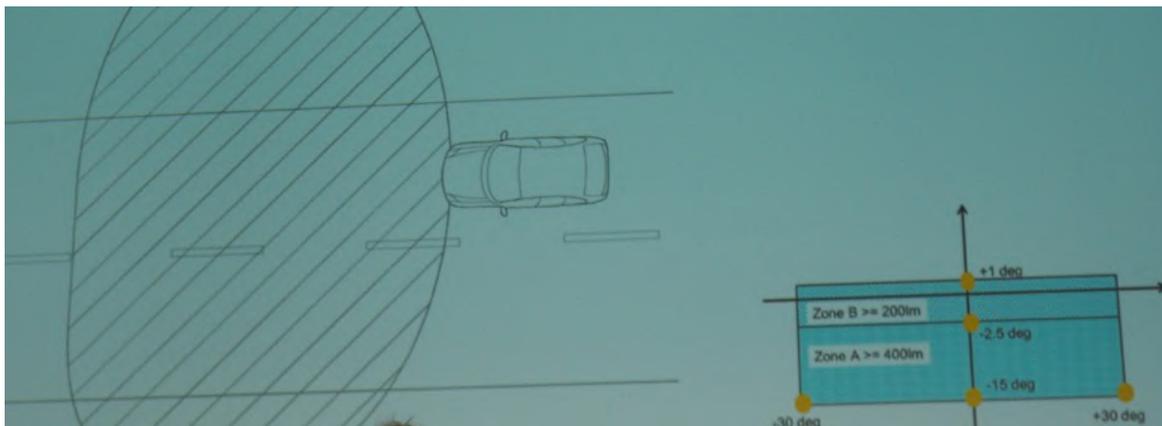
Dr. Neumann is presenting an alternative for lighting systems reusing the base of ADB for these extended uses in cities.

Naturally, the new concept will have to be integrated in regulation, that was already strongly simplified from 6 regulations and 24 beam patterns before, 1 regulation and 23 beam patterns today, and 1 regulation and 16 beam patterns tomorrow with the stage 2 simplification process.

The base of the idea is to consider that future vehicles and particularly autonomous vehicles will be equipped with many sensors to know everything about their environment. Speed, type of road, speed limit, external light, weather conditions, all other road users etc. will be known and so all the parameters to define the best light pattern will be available. In these conditions, only one regulation with a base beam and an intelligent ADB used permanently in every situation is possible.

The corresponding base beam is defined for use on motorways particularly during rush hours with a dense traffic. In these conditions, a symmetric beam is better avoiding glare for other drivers.

This beam defined as a minimum for safety will have to perform at least 200 lm in the area between -2.5° and $+1^\circ$, and 400 lm between -15° and -2.5° and could be an alternative to the existing UN Regulation to achieve minimum performance instead of old standards.



Naturally, the base beam must be used with an ADB system. For these future versatile ADB useable in every situation and every condition with no minimum speed limit, its validation and perhaps official approval could be done in the future through a simulation tool considering many traffic scenarios and concluded by a figure of merit.

Currently, a task force in GTB has started to study this idea for a feasible solution for the future.

This new proposal would have the advantages of being fully automatic, adapted for mixed traffic with AVs and traditional cars, saving energy with the basic beam in dense traffic, and could be the basis for a future harmonisation including the USA.

Future of Automotive Headlamps - Light for Sensors G. Böhm (ZKW)

Cameras and sensors are more and more used for ADAS and future autonomous vehicles. Their performance and particularly for cameras their detection rate and detection reliability are increased by an optimal lighting. Lighting will have so to be developed no more only for human eyes but also more and more for cameras.

Currently, headlamps are targeted to enhance the driver's view at night with AFS, or ADB, to enhance the visibility of road users with DRL or PL, to communicate driver's decisions with TI, to alert the driver with marking light while headlamps are also key components for styling. The question is how headlamps can support imaging?

Autonomous driving needs to be safe. But today, radars and lidar are limited in some situations.

At night particularly, a coordinated high-resolution lighting/video systems could much better recognise objects and identify them with colour, texture, and 3D information. For that, a tailored adaptive scenery illumination aimed to strongly improve the image and a high-resolution camera can provide a significantly improved information.



ZKW did tests with cameras set up at headlamp position, with adaptable aiming and field of view. For ZKW, a headlamp camera vision has several advantages as a direct coordination with lighting, a better observation of road markings and close up cars, a high disparity for distance calculation and could offer side views.

Another test was done for pedestrian detection between low beam and ADB with a camera having to detect and

recognise them. The confidence level with Low beam was only at 50%, while climbing to 96% with ADB.

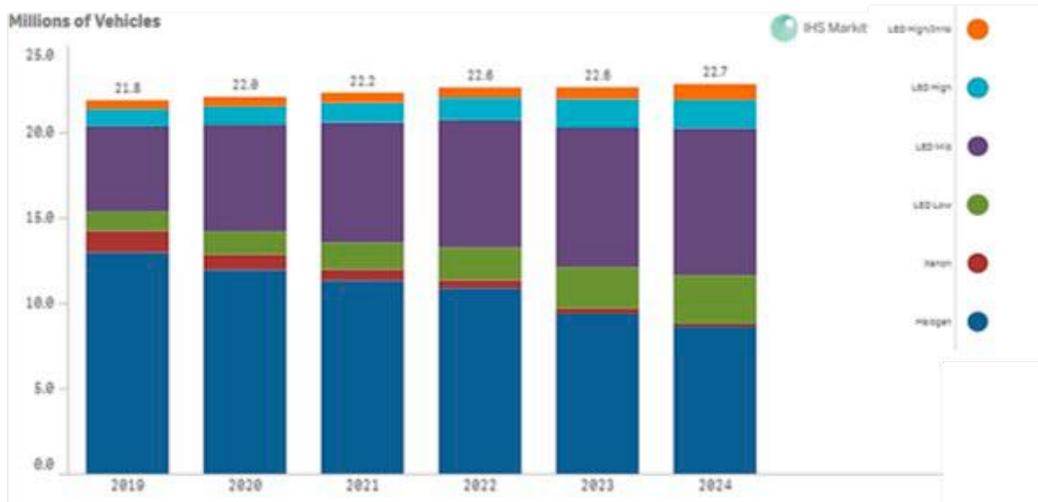
For the coordination and cooperation of imaging and illumination, a close loop logic must be established. For instance, some sub region can be identified where fine resolution illumination could considerably support the video system.

To improve the visibility from cameras, ZKW proposes a solution with integration of a forward and a side view in each headlamp. NCAP 2025 will for instance need a multi angle vision and a lone camera installed behind the windshield could have the view blocked by obstacles while cameras in headlamp will see the crossed lane much before the driver's view.

From Best-Cost to High Resolution: LED Matrix Applications

A. Austerschulte (Automotive Lighting)

The trend in Automotive Lighting is to use more and more LEDs and more and more innovative solution as ADB as seen in this chart from HIS:



To support the trend for more matrix beam implementation, Automotive Lighting proposes standard and compact modules covering three different low beam options (650lm, 800lm, 900lm) and three high beam options (Mono HB, 7 segments, 12 segments).

Matrix beams also improve their technical properties between illuminated segments and tunnels allowing to get full advantage of the 25% increased performance of the segments while the lens height can be reduced to 50mm. A range of 12 to more than 30 segments can also be realised in this module family, that can also be realised with reflection systems.

And for higher range applications, a large pallet of solutions with LED arrays integrating thousands of pixels till multi-million pixel systems will be present on the market.

Another important factor for Matrix beam adoption will be the generalisation of cameras in cars. This will be pushed by the obligation to install AEBS (Advanced Emergency Braking Systems) that could use LIDAR or Radar, but more often cameras. In Europe, it is already decided by regulation, and in USA, NHTSA announced that US automakers have agreed to include this device as standard in 2022.

In summary, more affordable and more attractive matrix beam systems as well as the presence of cameras for other functions inside cars will reduce the cost barrier and increase the attractiveness of matrix solutions in the future.

Three Awards at ISAL

ISAL awarded at the end of the symposium the best presentations : paper, lecture, and poster.
The winners received the awards from Audi's Michael Hamm.

Best paper

**Investigation of Pedestrian Behavior to 3 Encounter Scenarios with AV
(Tino Singer, TU Darmstadt L-Lab)**



The best lecture

Digital OLED for taillighting from Audi



The Best poster

Visibility Improvement Using Guide Function of Turn Signal Lamp (Hye-Jin Han, SL Corporation)



Many traffic accidents occur at road junctions, some of them because other drivers or pedestrians can't see or recognise the intended direction change of the vehicle.

SL, in cooperation with Yeungnam University, have developed a turn signal guide light to improve visibility of the turn signal. The experimental results showed better identification time when both direction-indicator lamps and the new turn signal guide lights versus conventional direction-indicator lamps alone.

A guide function of turn signal lamp was developed to project a marking pattern on the road to indicate the turning direction of the vehicle. Han and her team evaluated the recognition time and gaze points in three different situations to find out the effect of the guide function on the judgment of turning direction. They investigated the visibility and glare level of the guide function of the turn signal lamps using the prototype devices.

14 graduate students and 4 faculty members of Yeungnam University participated in the experiment. The team measured the time taken to recognise the direction of turning and observed the gaze points of a pedestrian positioned at a right front distant point from the right-side signal indicator and of a following driver position at a right rear distant point. The result from the T-junction road showed that the turn signal lamp with guide function significantly reduced the detection time of the turning direction. Compared with the turn signal only condition, average response time to the turn signal with guide lamp significantly decreased.

Another representative situation to evaluate the visibility of the turning signal is a lane change of a preceding vehicle. The comparison between each condition show that the guide lamps were helpful to recognise the direction of lane change. The difference was significant only at the right side.

For the evaluation of the glare effect, there was no difference in the discomfort glare score when the guide lamp was used and its directional angle was kept below 15°, compared to the case where only the conventional turn signal lamp was used. When we compared the total glare from the two conditions on the dry and wet surface, the results were almost the same.

The results of this study show that the guide function of turn signal lamp is effective to improve the visibility and it could reduce vehicle accidents and increase pedestrian safety.

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Car Makers

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 Audi, Germany
 Bentley, UK
 BMW, Germany
 FCA, USA
 Daimler, Germany
 Ford, Germany
 GM, USA
 Great Wall, China
 Harley-Davidson, USA
 Honda, Japan, USA
 Hyundai Motor, Korea, Europe
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 Mahindra Mahindra, India
 Nio, China
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 Opel, Germany
 Porsche, Germany
 PSA, France
 Renault, France
 SAIC TC, UK
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 Seat, Spain
 Skoda, Czech Republic
 Toyota, Japan, Europe, USA
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Univ., labs, Consultants

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 Institut d'Optique, Fr.
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 YoungNam University, South Korea
 Mr Shunxing Wang, China

Set Makers and Tier 1s

AL, Germany, USA
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 Tianchong, China
 Truck-Lite, USA
 Valeo, France, Spain, China
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Light Source Suppliers

Anrui Opto, China
 Diodes Dynamics, USA
 Dominant Opto Tech., Malaysia
 Everlight Electronic, Taiwan, Germ.
 Excellence Opto Inc., USA, Taiwan
 LG Innotek, South Korea
 Lumileds, Nederlands
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 ON Semiconductor, Europe, Asia, US
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 Synopsys, USA, Germany
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 WL Gore, USA
 Zollner, Germany

MAIN DVN REPORTS

List of Main DVN Reports 2008-2017

Hella company profile	Korea Lighting Market
Audi company profile	SL Corp profile
AL company profile	ADB/Matrix Beam
DRL, brand signature	J.W. Speaker Profile
Valeo company profile	2015 Geneva Auto Show
Koito company profile	ADAS and Lighting
China lighting market	India Car Industry and Lighting Market
The Wonderful World of Passenger Car lighting Regulations	Advanced Motorcycle Lighting
Tier 2and3 contribution on automotive lighting	IAA Auto Show 2015
ZKW company profile	ISAL 2015
Simulations in automotive lighting	Peterson Manufacturing
Mercedes-Benz profile	NAIAS Auto Show
LED technologies in Automotive Head lighting	Delhi Auto Expo 2016
LEDs Thermo-Electrics	DVN Delhi workshop
Interior Lighting	Geneva Auto Show 2016
BMW and lighting	Vision of lighting 2025-2030
Lighting and Driver Assistance	DVN Tokyo workshop
OLED technology	Automotive lighting Regulations worldwide
Materials in lighting	New ADB technologies
Laser Head lighting	Mondial Paris Auto Show
Peterson Manufacturing	VISION Congress Vehicle Lighting in USA
Automotive lighting Regulations worldwide	Vision of lighting 2025-2030
Simulation Tools	New ADB technologies
Israeli Startups	Interior Lighting
Jaguar Land Rover and lighting	ISAL symposium
IAA Frankfort autoshow	Shanghai autoshow

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NAIAS and CES autoshows 30-01	Camera technologies 25 - 07
DVN Munich Workshop 27-02	Varroc profile 02-10
Geneva autoshow 27-03	Mondial Paris Autoshow 23 - 10
Engineering companies involved in lighting 24-04	VISION congress 04 - 12
Japanese lighting market 22-05	Volkswagen profile 18 - 12
DVN Tokyo Workshop 26-06	

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Geneva autoshow.....19 March	IAA Frankfort Autoshow.....17 September
Volkswagen profil.....2 April	ISAL.....15 October
Shanghai Autoshow.....7 May	Automotive lighting in US.....12 November
Materials in automotive lighting...28 May	Interior lighting.....10 December
Status of w/w Regulations.....18 June	