Submitted by the expert from GTB

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agenda item 10)

Lighting for automated vehicles – Discussion on ways forward

For GTB Forum in
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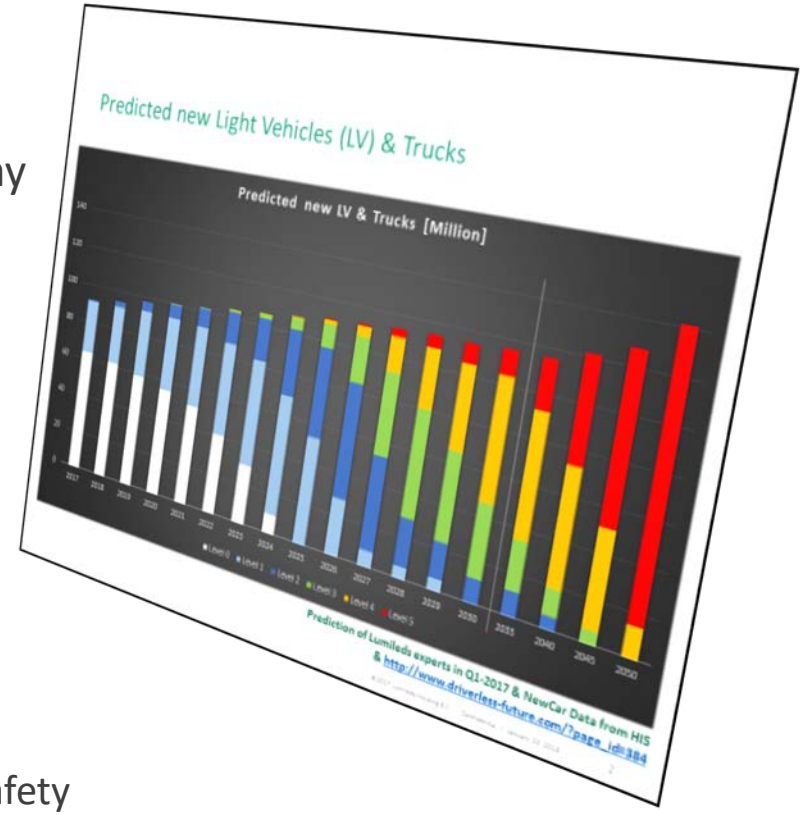
GTB
The International Automotive Lighting and Light Signalling Expert Group
Groupe de Travail "Bruxelles 1952"

Autonomous vehicles will come!

But what, when, and how?

- Various driver-assistance functions applicable today
  - In the oncoming years, connectivity and digitalization create a new scope of safety improvements of traffic
  - Lighting appears as SO LOGICAL to support safety



- The timeline varies!
  - Digitalization will support various assistance functions – now!
  - Automation will increase in the early decade
    – whilst mixed traffic is the subject to handle safety
  - Autonomous operations will take over from the second half of the decade

- AVIP VIDEO –
  - https://www.youtube.com/watch?v=MU74wK_RlTo

Disturbed Communication:

e.g.

- No Gestures from AV
- No Eye-contact with AV possible
- …..

AV:

Lagström, T. & Malmstem Lundgren, V. (2015), **“AVIP”,** Autonomous vehicles’ interaction with pedestrians. An investigation of pedestrian-driver communication and development of a vehicle external interface, MSc Thesis. Chalmers University of Technology, Gothenburg. Sweden.

ADS= Automated Vehicles =AV

~~**Autonomous**~~

ADS = Automated Driving Systems = **"AVs"**

Level 3-5 AV- SAE J3016 Terminology

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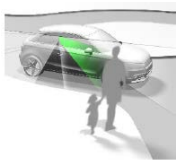
Lighting for **automated vehicles**

- Special Needs for automated vehicles or road users in interaction with them

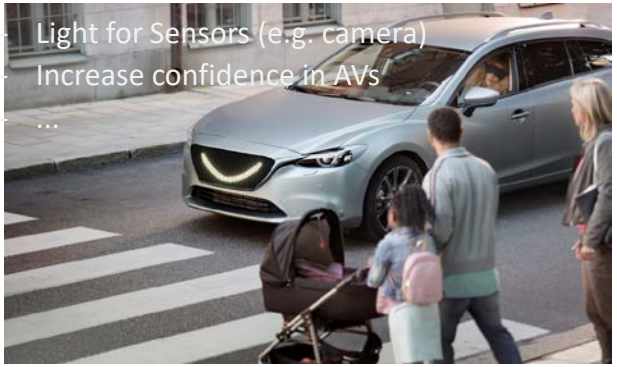
  - Indication of Status of AV (ON/OFF)

  - Indicating Future Intent of AV

  - Signals for Interaction with other road users (e.g VRU was noticed, giving right of way,…)



  - Others:
    - Light for Sensors (e.g. camera)
    - Increase confidence in AVs
    - …



OVERVIEW- AV Lighting & Signalling

Studies	Org.	Reg./Gov.
AVIP Ghost Driver CityMobil2 Duke-Display ISO(Ford) interACT NHTSA “AV Intent” CLEPA-LSS …	SAE ISO GTB CLEPA – LSS OICA …	U.S. DOT NHTSA ITS WP.1(?) WP.29(?) Germany … …

……..others? Pls. forward information;)

Conceptual Differences - Field studies used „Fake AVs“ „Wizard of Oz“AVs

NO VISIBLE DRIVER ⇔ VISIBLE DRIVER

„Ghost Driver“/“Ford“

NO VISIBLE DRIVER
No Human Interaction possible

⇔

„AVIP“

„FAKE DRIVER“ (e.g.Dummy steering wheel)
Communication disturbed

→ Following Studies were analyzed by Vissers /SWOV about their results:

Vissers, L.; Kint, S. van der; Schagen, I. van; Hagenzieker, M.: **Safe interaction between cyclists, pedestrians and automated vehicles - What do we know and what do we need to know?,** SWOV Institute for Road Safety Research, The Hague, December 2016

„AVIP“ Study Sweden

Field Study – VISIBLE DRIVER

Communication:
- I’m in automated driving mode (AD mode),
- I’m about to yield,
- **I’m resting,**
- I’m about to start

Result:
Pedestrians were less willing to cross the street when the driver of the approaching car was inattentive or showing uncommon driver behavior.

Lagström, T. & Malmstem Lundgren, V. (2015), **“AVIP”,** Autonomous vehicles’ interaction with pedestrians. An investigation of pedestrian-driver communication and development of a vehicle external interface, MSc Thesis. Chalmers University of Technology, Gothenburg. Sweden.

„Ghost Driver“- US-Stanford –

Field study - NO VISIBLE DRIVER

Communication:
- no interaction Displays studied

Result:
A driverless car did not interfere with a smooth interaction. Only when the vehicle misbehaved, some pedestrian became more hesitant.

D. Rothenbücher; J. Li; D. Sirkin; B. Mok; W. Ju: **Ghost driver**: A field study investigating the interaction between pedestrians and driverless vehicles, 2016 25th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN), New York, NY, 2016, pp. 795-802.

„CityMobil2“ *–EU*

Questionnaire with Automated Bus

Communication:

- whether it is stopping
- **whether it is turning**
- **how fast it is going**
- whether it is going to start moving
- whether it has detected me

Result:
Pedestrians want to be notified by auditory signals and lights when they are seen by an automated vehicle.

1.Merat, N., Madigan, R., Louw, T., Dziennus, M. and Schieben, A. (2016) What do Vulnerable Road Users think about ARTS. CityMobil2 final conference. Donostia, San Sebastian, Spain.

„Duke-Display“ USA - Duke University

Field study with Communication Display

Communication:

-cross advisory
-don‘t cross advisory
-SPEED

Result:
Pedestrians tend to rely on exisiting crossing strategies than responding to displays on the car.

M. Clamann, M. Aubart, M.L. Cummings: Evaluation of Vehicle-to-Pedestrian Communication Displays for Autonomous Vehicles,
https://hal.pratt.duke.edu/sites/hal.pratt.duke.edu/files/u10/Clamann_etal_TRB2016.pdf , Duke University, July 2016

UPCOMING Studies

„Ford/ISO“ –US, Arlington

Field Study - NO VISIBLE DRIVER

Communication as ISO:
- Driving autonomously
- yielding
- preparing to drive

Result:
Not yet published.

Video: https://www.youtube.com/watch?v=boqG7Ss7chI

John Shutko, ISO/TC 22 SC39 WG 8 N3678, ISO/NP TR 23049 Road Vehicles -- Ergonomic aspects of external visual communication from automated vehicles to other road users, https://standardsdevelopment.bsigroup.com/projects/9017-00782 (accessed Sept. 2017)

„interACT“ – EU funded

interACT
Designing cooperative interaction of automated vehicles with other road users in mixed traffic environments

Designing cooperative interaction of automated vehicles with other road users in mixed traffic environments

Results:
Not yet published, but
Requirments and Definition of interACT scenarios in Deliverable 1.1. available

https://www.interact-roadautomation.eu/

interACT Project Coordinator Anna Schieben Deutsches Zentrum für Luft – und Raumfahrt e.V. (DLR) / Institute of Transportation Systems / Lilienthalplatz 7 38108 Braunschweig, Germany
Anna.Schieben@dlr.de

Ford and Virginia Tech Transportation Institute are testing a Ford-designed lighting method for self-driving cars
ISO/TC 22 SC39 WG8 „Ergonomic aspects of external visual communication from automated vehicles to other road users“

„AV Intent“ *–US,*

US project “AV Intent – Automated Vehicle Communication and Intent with Shared Road Users”

Sponsor: NHTSA

Contractor: UMTRI

NHTSA
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

Twining partner of

interACT
Designing cooperative interaction of automated vehicles with other road users in mixed traffic environments

Result:
Not yet published.

CLEPA-LSS

„Autonomous driving vehicles and the role of new lighting functions in the traffic space”

In coop with TU Darmstadt on basic requirements for lighting on automated vehicles

Light Sight Safety

CLEPA-LSS in coop with TU Darmstadt on basic requirements for lighting on automated vehicles

Result:
Not yet published.

….and perhaps many more!

Neutral Summary of following Studies

Comprehensive summary by Vissers* et al over diff. available studies:

"**Safe interaction between cyclists, pedestrians and automated vehicles - What do we know and what do we need to know? "**

- *VRU are cautious in interaction with AV and worried about is "skills"*
- *appreciate messages and/or signals whether car has detected and what it intends to do*
- *however, which exact messages need to be brought about and the method of communicating them are not yet settled and requires further study.*

***Vissers**, L.; Kint, S. van der; Schagen, I. van; Hagenzieker, M.: **Safe interaction between cyclists, pedestrians and automated vehicles - What do we know and what do we need to know?,** SWOV Institute for Road Safety Research, The Hague, December 2016

Vissers* analyzed in 2016 3 studies – "CityMobile2", "AVIP" & "Duke Display"

- "**CityMobil2"** (Merat et al. (2016 …they found that pedestrians, as well as cyclists, **want to be notified by auditory signals and visual lights** when they are 'seen' by AV

.

- "**AVIP"** study (Malmsten Lundgren et al. (2017)): pedestrians **expect to get confirmation** from the 'driver' of the car, even if he is not the one who is actually driving the car. …Results showed that **pedestrians are calmer and more willing to cross the street if they are informed about the intentions of the automated vehicle to stop.**

- **"Duke-Display"** study (Clamann, Aubert & Cummings (2016)): … pedestrians are more likely to **rely on existing crossing strategies than on the novel displays** … At the same time,… a **majority of the participants** believed that an **external vehicle display is necessary** for **AV-VRU communication**."

Pedestrian and Cyclist Interaction with automated vehicles			Method: Field Experiments only	© Vissers
Keyword	**Author**	**Research Question**	**Description**	**Results**
AVIP	Lagström & Malmsten Lundgren (2015); Malmsten Lundgren et al. (2017) and Habibovic et al. (2016)	Will there be new communication needs to warrant safe interactions with automated vehicles	13 participants had to indicate whether they were comfortable crossing the street in case of manually-driven and (Wizard-of-Oz simulated) automated vehicles. Additionally, 50 participants participated in a survey that showed pictures of a vehicle that was being driven manually or using a Wizard-of-Oz setup. Their (un)willingness to cross the street and their emotional experience were explored.	Pedestrians were less willing to cross the street when the driver of the approaching car was inattentive or showing uncommon driver behavior.
Ghost Driver	Rothenbücher et al. (2016)	How will pedestrians and bicyclists interact with automated vehicles when there is no human driver?	67 participants encountered a vehicle that appeared to have no driver	A driverless car did not interfere with a smooth interaction. Only when the vehicle misbehaved, some pedestrian became more hesitant.

Communication needs in interaction with automated vehicles			*Methods: all methods*	© Vissers
Keyword	**Author/Method**	**Research Question**	**Description**	**Results**
„Duke-Display“	Clamann et al. (2016) *Method:Field Experiment*	What is the effectiveness of new methods of vehicle-to-pedestrian communication	50 participants made crossing decisions in interaction with automated vehicles with different messages displayed on a forward facing display. Response times were measured.	Pedestrians tend to rely on exisiting crossing strategies than responding to displays on the car.
„AVIP“	Lagström & Malmsten Lundgren(2015) *Method:Field Experiment*	Can pedestrians recognize an Automated Vehicle Interaction Prototype (AVIP) and can the vehicle provide any aid for pedestrians in the interaction with an automated vehicle	9 participants interacted with an automated vehicle that informed the pedestrian about ist mode and intentions using a LED-strip in the windshield displaying different communication patterns.	The AVIP helped pedestrians understand the intentions of the automated vehicles. Participants were more willing to cross the road before the vehicle stopped and they were calmer when doing so.
„CityMobil 2“	Merat et al. (2016) *Methode:Questionnaire*	What do vulnerable road users think about Automated Road Transport Systems (ARTS) and how do they want to interact and communicate with ARTS?	664 participants answered 20 questions about demographics, Unified theory of Acceptance and Use of Technology(UTAUT), and questions related to interaction/informaton signals	Pedestrians want to be notified by auditory signals and lights when they are seen by an automated vehicle.
FORD/ISO	*Not yet available*	*Not yet available*	*Not yet available*	*Not yet available*

WORK OF Standardization ASSOCIATIONS

- **SAE J3134** (WIP -Work in Progress) Autonomous Vehicle Lighting
  - Chair: Romeo Samoy – NAL
  - **Feel free to join!**
  - Format: SAE Recommended Practice

Proposed Communication:

- **Details** available for **participants of SAE TF** and **changing**,

- SAE discusses a **distinct place approach** (e.g. top of windshield) and „standard color“ or a **„distinct color approach“** to make it US compliant („ **does not impair“ with** FMVSS 108 regulated functions) and **simple behaviour**.

→ One possible example on next slide how such a simple communication could happen:

Only an example how SAE proposal could look like !

STATUS: SUMMER 2017!

ISO/TC 22 SC39 WG 8 N3678, ISO/NP TR 23049

Road Vehicles -- Ergonomic aspects of external visual communication from automated vehicles to other road users,

Chair: John Shutko, Ford

Scope:

... recommended that the **communication should be common across industry.**

Legibility, Learnability of these systems are **main focus, limiting the number of signals** and **ensuring** they are **distinct and salient,**

... providing a **positive impact on societal acceptance.**

Active autonomous driving: Solid white light to indicate vehicle is driving autonomously

Yielding

Yielding: Two white lights that move side to side, indicating vehicle is about to yield to a full stop

Preparing to Drive

Starting to Go: Rapidly blinking white light to indicate vehicle is beginning to accelerate from a stop

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Active autonomous driving: Solid white light to indicate vehicle is driving autonomously

NATIONAL GUIDELINES

US DOT/NHTSA published 2016 **"Federal Automated Vehicles Policy"**:

"… HMI design should also consider the need to **communicate** information **to pedestrians, conventional vehicles**, and automated vehicles regarding *the* ***HAV's state of operation relevant to the circumstance (e.g., whether the HAV system identified a pedestrian at an intersection and is yielding)…..***"

In 2017 NHTSA updated to "A Vision for Safety 2.0"
&NHTSA plans for 2018 a version „3.0"

Communication:
- whether Identifying Pedestrian at an intersection
- whether Yielding for Pedestrian
& think about Communication with conventional vehicles and other AVs

From: https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety

Overview **National Guidelines – USA/NHTSA**

DEPARTMENT OF TRANSPORTATION

National Highway Traffic Safety Administration

49 CFR Part 571

[Docket No. NHTSA–2018–0009]

Removing Regulatory Barriers for Vehicles With Automated Driving Systems

AGENCY: National Highway Traffic Safety Administration (NHTSA), Department of Transportation (DOT).

ACTION: Request for comment (RFC).

2018 NHTSA ASKED „REQUEST FOR COMMENT“ about topic

„Removing Regulatory Barriers for Vehicles With Automated Driving Systems“

https://www.gpo.gov/fdsys/pkg/FR-2018-01-18/html/2018-00671.htm

e.g. Question 15:

- 15. Do the FMVSS create testing and certification issues for vehicles with ADSs other than those discussed above? If so, which FMVSS do so and why do you believe they present such issues? **For example, FMVSS No. 108,** ``Lamps, reflective devices, and associated equipment,'' could potentially pose obstacles to certifying the compliance of a vehicle that **uses exterior lighting and messaging, through words or symbols,** to communicate to nearby pedestrians, cyclists and motorists, such as at a 4-way stop intersection, **the vehicle's awareness of their presence and the vehicle's willingness to cede priority of movement to any of those people**. If research is needed to eliminate the barriers in an appropriate way, please describe the research and explain why it is needed. **Are there other lighting issues that should be considered? For example, what lighting will be needed to ensure the proper functioning of the different types of vehicle sensors, especially cameras whose functions include reading traffic control signs?**
  - Deadline for written comments: March 5, 2018

Ethics commission of **Federal Ministry of Transport and Digital Infrastructure in Germany created 20 rules:**

- "5. … the *entire spectrum of technological options* **– for** instance …., ***signals for persons at risk***, ….**–** *should be used and continuously evolved*. The significant enhancement of road safety is the objective of development …, ***posing as little risk as possible to vulnerable road users***. "

- "16. **It must be possible to clearly distinguish whether a driverless system is being used** or whether a driver retains accountability with the option of overruling the system.

As OEMs designing an AV should respect these **guidelines** it seems evident that a standard needs to be developed in the US and in Europe.

Communication:

- signals for persons at risk (rule 5)
- clarity who is under control (rule 16)

Summary & Outlook

Majority of studies show:

- VRUs want to have with AVs a special communication

- e.g a **reliable acknowledgment of detection** and **communication about intended future actions of the AV** and the **state of the AV** (ADS ON).

- **Communication needs to be clear and learnable**

…. what will new studies find out?

- **Should basic communication signals be standardized** and become **mandatory ?** (e.g. ADS status, ADS intentions,...)
- **Should additional communication signals** become **optional** but **standardized, if beneficial for the safety of VRUs/other drivers?**
- **The communication needs** of "**classic" driver** towards AVs is currently **less studied & needs further discussion** (e.g. Indication / communication to rear/ side/ other interaction tools/needs?)
- Other needs – e.g. for the police?

& Many other questions....

IS STANDARDIZATION IS NEEDED?