



ROAD MARKING SYSTEMS



ROAD MARKING SYSTEMS

A wireframe car, rendered in a glowing blue mesh, is positioned on a road. The road is depicted with a grid of lines and dashed white markings. The background is a dark, futuristic landscape with a grid of lines and a glowing blue light source. The overall scene is set against a dark blue background with a white curved border on the right side.

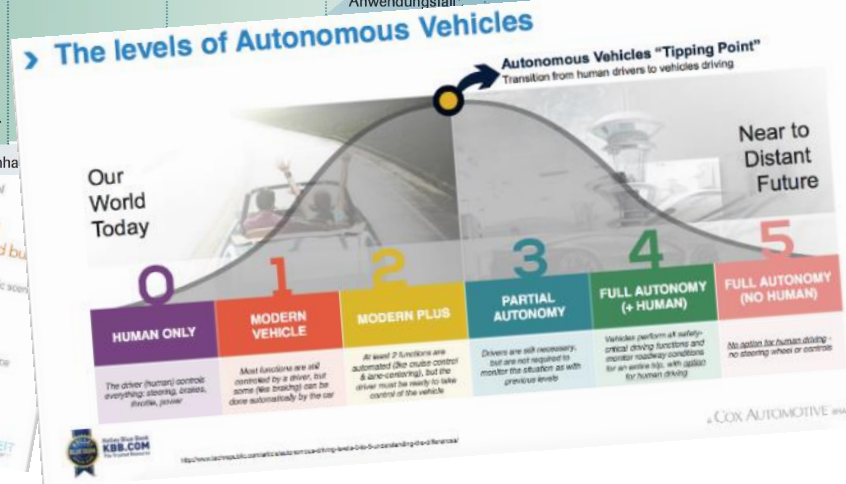
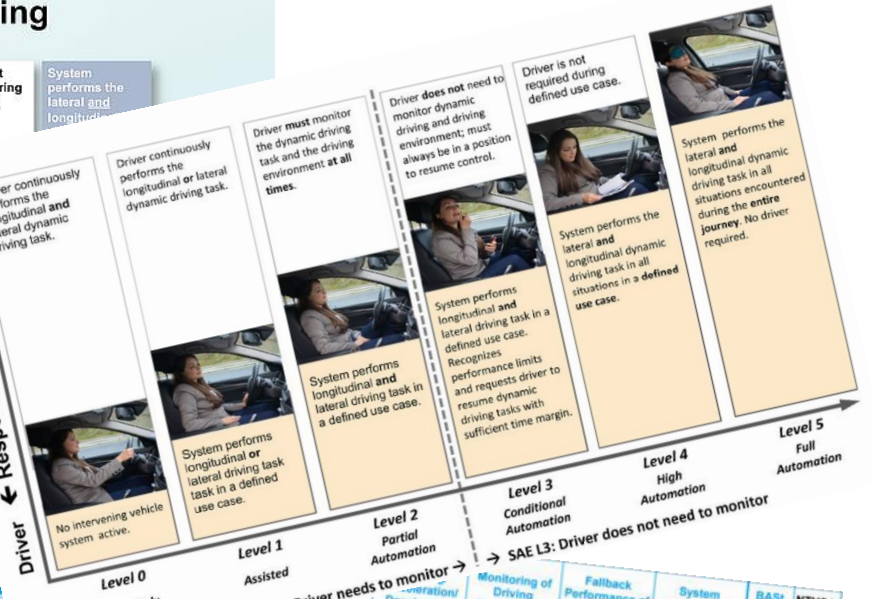
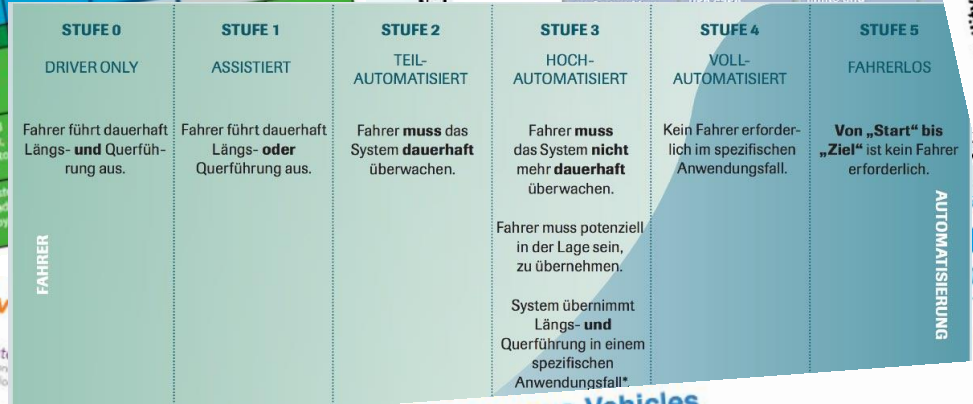
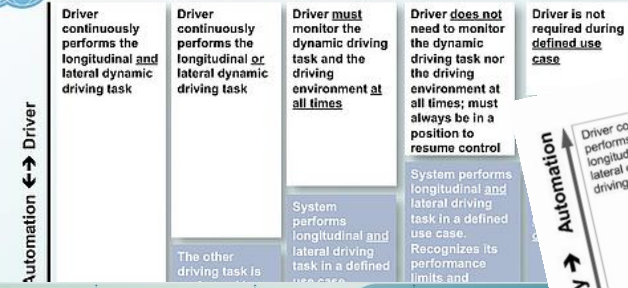
*Road markings and
autonomous driving –
or
back from the future*

LEVELS OF AUTONOMOUS DRIVING

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System Capability (Driving Modes)
Human driver monitors the driving environment						
0	No Automation	the full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task	System	Human driver	Human driver	Some driving modes
Automated driving system ("system") monitors the driving environment						
3	Conditional Automation	the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene	System	System	System	Some driving modes
4	High Automation	the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene	System	System	System	Some driving modes
5	Fully Automated	the full-time performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene	System	System	System	Some driving modes



Levels of Automated Driving



SAE Level	Name	Execution of Steering and Acceleration/Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System Capability (Driving Modes)	BASt Level	NHTSA Level
0	Driver Only	Human Driver	Human Driver	Human Driver	N/A	Driver only	0
1	Assisted	Human Driver and Systems	Human Driver	Human Driver	Some Driving Modes	Assisted	1
2	Partial Automation	System	Human Driver	Human Driver	Some Driving Modes	Partially Automated	2
3	Conditional Automation	System	System	Human Driver	Some Driving Modes	Highly Automated	3
4	High Automation	System	System	System	Some Driving Modes	Fully Automated	3/4
5	Full Automation	System	System	System	Some Driving Modes	Fully Automated	3/4

LEVELS OF AUTONOMOUS DRIVING



LEVEL 0

Driver responsible for all driving tasks.

LEVEL 1

Advanced Driver Assistance System (ADAS) can assist by steering or braking/braking, but not both at the same time.

LEVEL 2

ADAS is able to simultaneously control steering and braking/acceleration under certain circumstances.

LEVEL 3

Automated Driving System (ADS) may take over all aspects of the driving task under certain circumstances.

LEVEL 4

ADS is responsible for all driving tasks as well as environmental monitoring under certain circumstances.

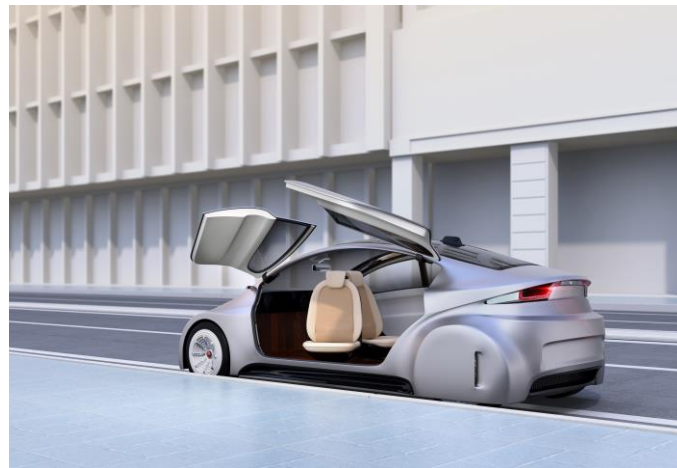
LEVEL 5

ADS takes over all driving tasks.

LEVEL 5
Human is a passenger.

LEVEL 2 - 4
In each level a takeover by the human is necessary.

FULLY AUTONOMOUS LEVEL 5

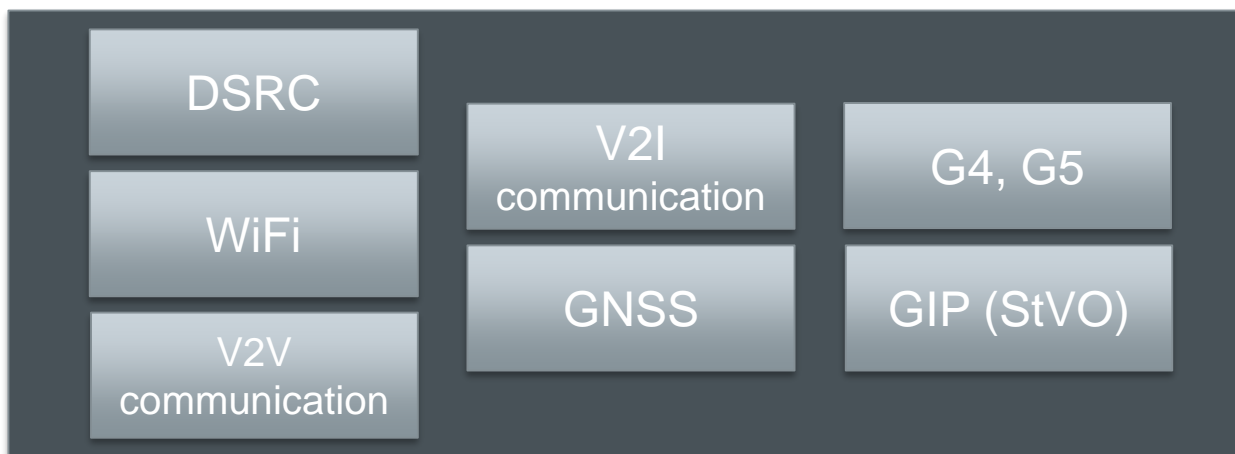
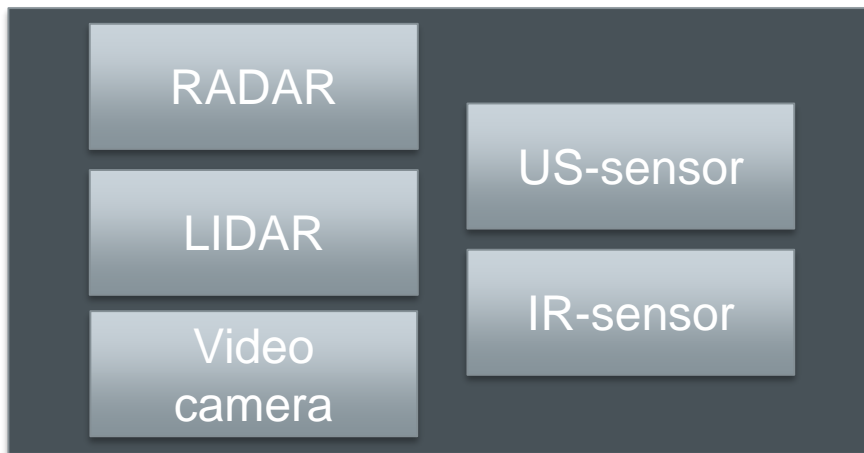


ASPECTS LEVEL 5

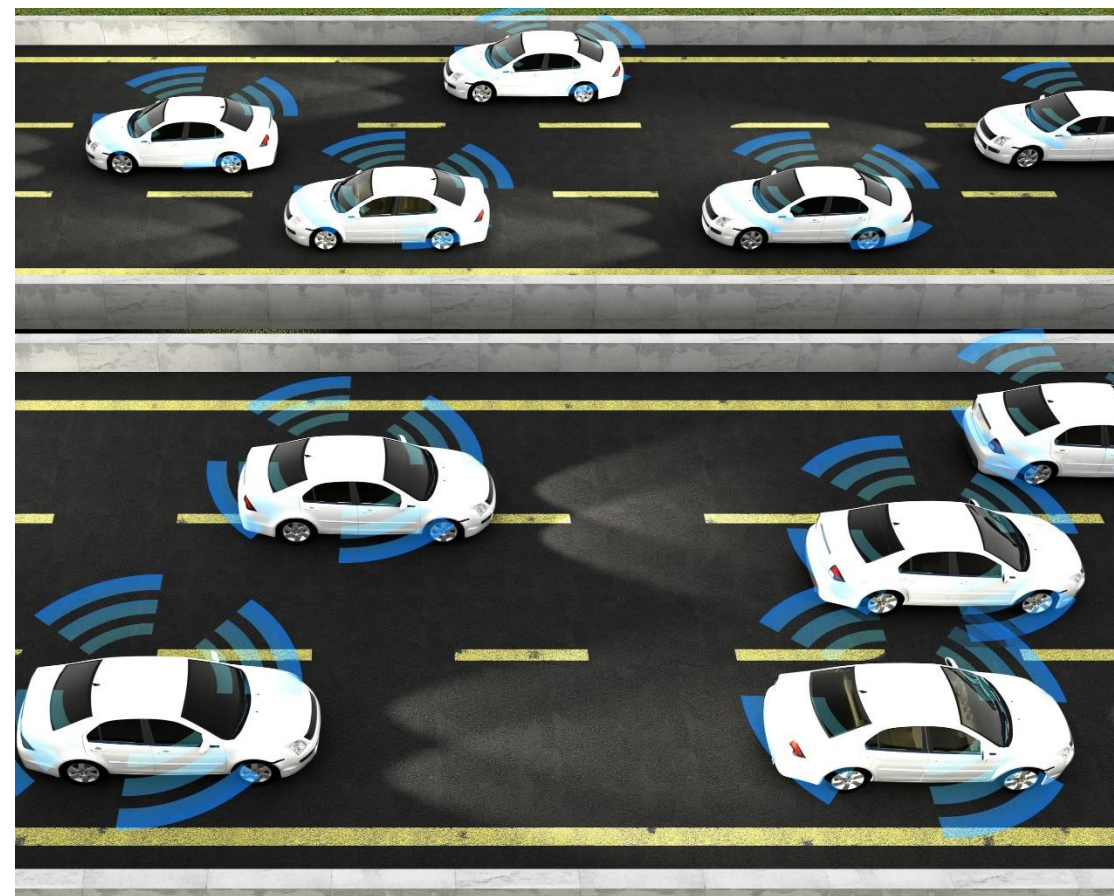
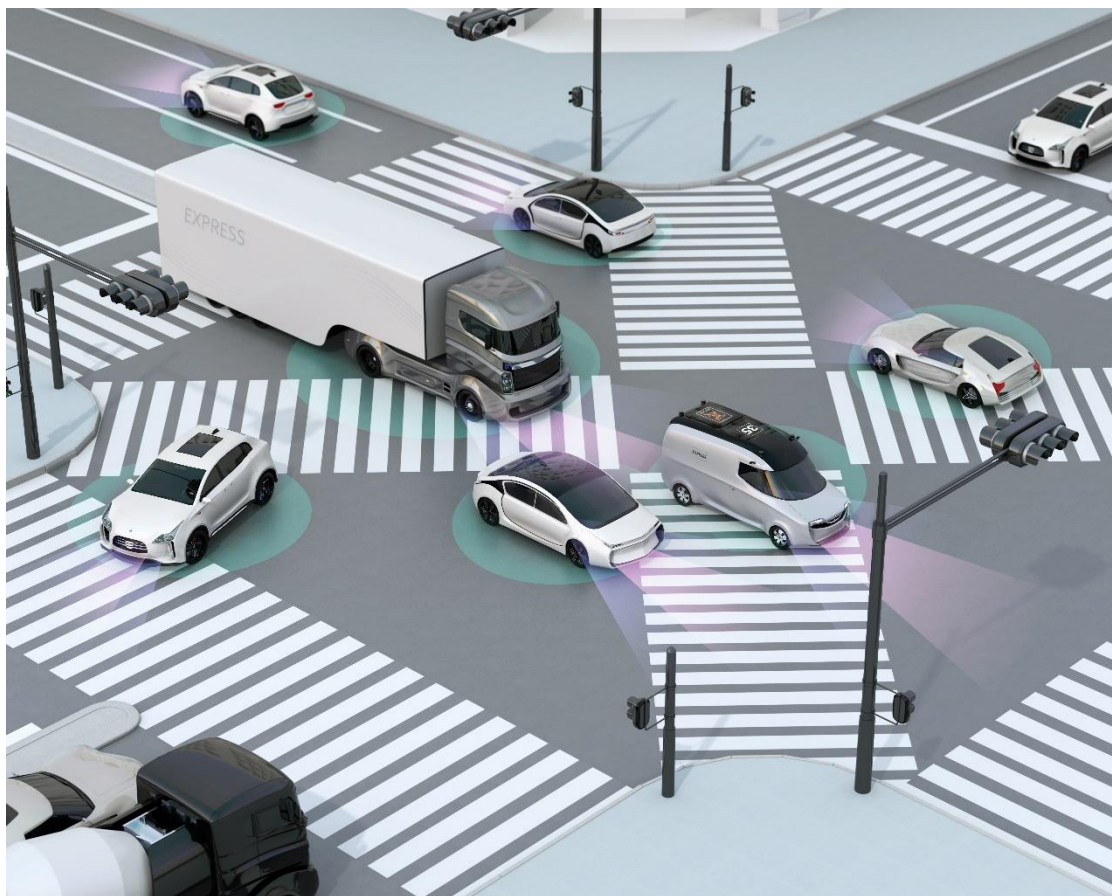


SENSORS

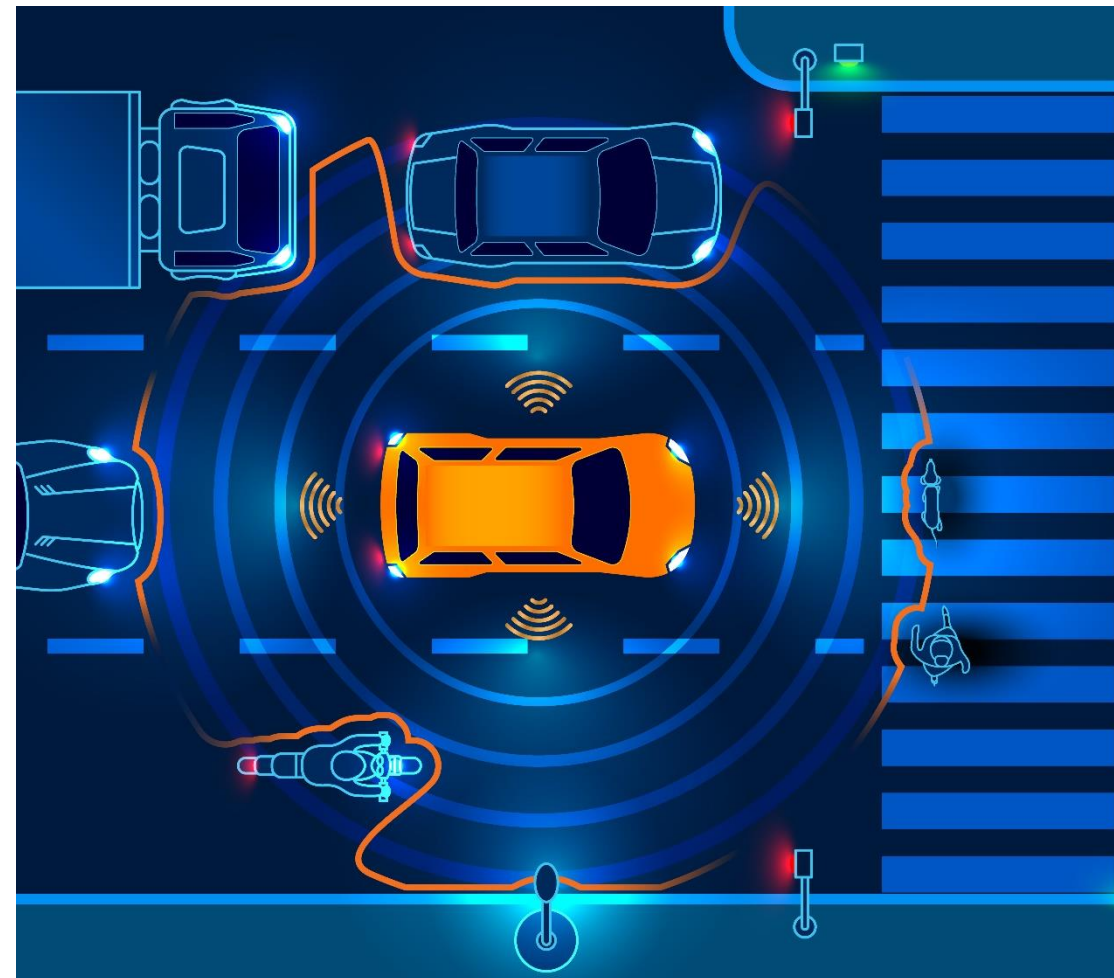
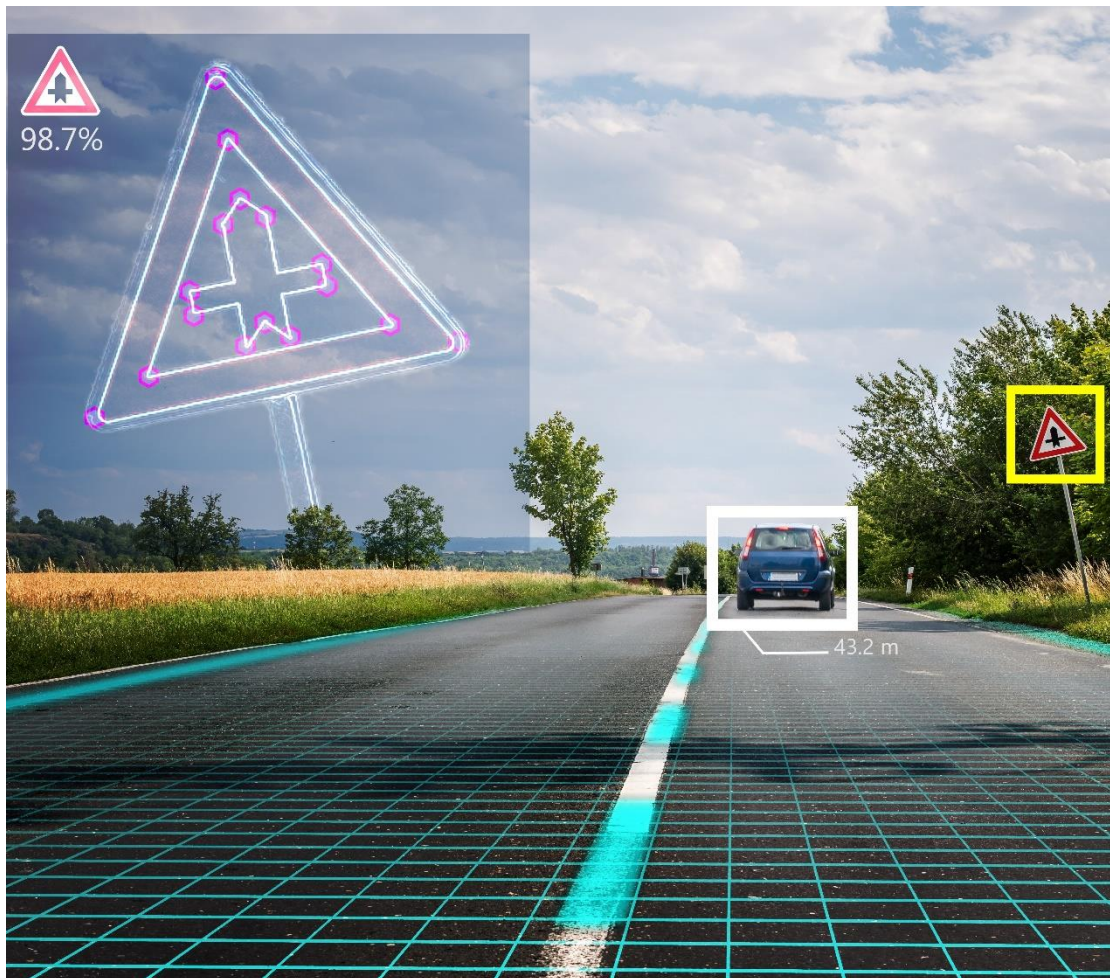
LEVEL 5 - TECHNOLOGY



V2V COMMUNICATION LEVEL 5 - TECHNOLOGY



V2I COMMUNICATION LEVEL 5 - TECHNOLOGY



WHAT DOES POLICY AIM FOR?

LEVEL 5 - POLICY



Road safety: Vision Zero

- Increase in road safety
- Reduction of human driving errors
- 90% of all accidents are caused by human error



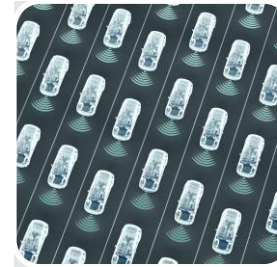
Reduction of emissions

- Reduction of fuel consumption and CO₂ emissions
- 23-29% reduction of fuel consumption on highways



Innovation

- Encouragement of innovation
- Competitiveness / Highly skilled jobs
- 56 minutes per day for other activities



Traffic management

- Optimization of traffic flow
- Pleasant and time-efficient driving
- 80% improvement in terms of traffic flow



Demographic changes

- Support of insecure drivers
- Mobility increase for ageing population
- Access to mobility for many different age groups

WHAT DOES POLICY NEED TO DO? LEVEL 5 - POLICY

- Legal issues
 - Insurance
 - Safety
- Approval procedure
 - From time x only allowance for level 5 vehicles



Merkel: Self-driving cars in 20 years duty (derStandard.at, 12 June 2017):

In 20 years we will only be allowed to drive independently with special permission. Humans are the biggest risk in terms of driving. Therefore, it is safer to let the technology take over in the future.



ACCEPTANCE LEVEL 5 - SOCIETY

- ▶ Value of owning a car is changing
 - ▶ Vehicle loses a symbol of status
 - ▶ Vehicle becomes a commodity
- ▶ Change from individual traffic to sharing culture
 - ▶ Car Sharing
 - ▶ Car2go
- ▶ Ethics



Could you imagine using an
autonomous vehicle?

Source: <http://www.bmvi.de/SharedDocs/DE/Publikationen/G/bericht-der-ethik-kommission.html>



VISION OR REALITY? LEVEL 5 - CONCLUSION

- ▶ Level 5 vehicles will become a reality faster than we currently believe
- ▶ Technologically, no longer a real challenge
- ▶ The last few percent to the exclusive level 5 will take longer than we think
- ▶ In between – a long transitional period and parallel traffic (levels 2-4)



ROAD MARKINGS AND ASSISTANCE SYSTEMS LEVELS 2 - 4

„The car can't find the lane markings! You need to paint the bloody roads here!“

Lex Kerssemakers
CEO Volvo Nordamerika

„Like the human eye, the technology can't work effectively if it can't see the road markings if they are worn out or hidden, or if they are confusing.“

EuroRAP, EuroNCAP

„We really need better lane markings. This is crazy.“

Elon Musk
CEO Tesla

„Lane markings are the rails for the self-steering car.“

EuroRAP, EuroNCAP

„They (self-driving car companies) actually said make sure you have really good paint lines. So, where there are lines, we have to make sure they're really good.“

Kirk Steudle
Director of Michigan's Department of Transportation

„We need to increase the time, distance, weather range and durability so that a machine or camera can 'see' the pavement markings.“

Tom Hedblom
3M

ROAD MARKINGS AND ASSISTANCE SYSTEMS

LEVELS 2 - 4

<https://thenextweb.com/contributors/2017/10/07/3-improvements-needed-make-autonomous-car-future-reality/>

<https://roadsensors.madebydelta.com/news/quality-road-marking-will-crucial-safety-self-driving-cars-future/>

<http://www.reflective-systems.com/future-proofing-road-markings/>

<http://automotive.electronicsspecifier.com/driver-assistance-systems/markings-roads-to-make-them-safer-for-self-driving-cars>

<https://www.bavc-automobilclub.de/de/component/k2/item/298-der-traum-vom-autonomen-fahren>

<http://www.reflective-systems.com/no-more-than-4-years-to-have-fully-autonomous-cars-on-the-road/>

<http://media.daimler.com/marsMediaSite/en/instance/ko/Second-leg-of-the-Intelligent-World-Drive-On-the-road-to-autonomous-driving-Mercedes-Benz-on-automated-test-drive-in-the-Shanghai-megalopolis.xhtml?oid=30028143>

<http://www.autonomes-fahren.de/strassenschaeden-autonome-fahrzeuge/>

<http://www.reuters.com/article/us-autos-autonomous-infrastructure-insig-idUSKCN0WX131>

<https://www.wired.com/2016/03/self-driving-cars-wont-work-change-roads-attitudes/>

<http://www.auto-motor-und-sport.de/news/autonomes-fahren-probleme-2016-11523070.html>

<http://www.tegget.de/autonomes-fahren.html>

<http://www.faz.net/aktuell/wirtschaft/neue-mobilitaet/autonomes-fahren-im-test-bei-mercedes-bmw-und-audi-14237392.html>

C-ITS PLATFORM LEVELS 2 - 4



C-ITS platform PHASE II

Cooperative Intelligent Transport Systems
towards **Cooperative, Connected and Automated Mobility**

FINAL REPORT
SEPTEMBER 2017

- ▶ Launched by the European Commission in 2014
- ▶ Phase II: 2016-2017
- ▶ Platform for the use of cooperative and intelligent traffic systems in the EU
- ▶ Goals
 - ▶ Development of a common vision
 - ▶ Interoperability of C-ITS along the entire value chain
 - ▶ Identification of the most important scenarios (V2V, V2I, CCAM)
- ▶ Representation of important stakeholders
 - ▶ About 200 experts
 - ▶ 9 working groups

C-ITS PLATFORM LEVELS 2 - 4

Extracts from the recommendations (S. 86-102)

- › Effective and sustainable maintenance of road infrastructure
- › Decent quality and clear visibility
 - › Highways
 - › Motorways
 - › Key cross-border routes (TEN-T network)
- › Clear visibility for vehicle sensors
- › Harmonization of standards



C-ITS platform PHASE II

Cooperative Intelligent Transport Systems
towards **Cooperative, Connected and Automated Mobility**

FINAL REPORT
SEPTEMBER 2017

AVAILABILITY: AUDI ACTIVE LANE ASSISTANCE LEVELS 2 - 4



Quelle: AUDI

CAMERA AND LIDAR LEVELS 2 - 4



REDUNDANCY



LIDAR – LIGHT RADAR LEVELS 2 - 4



- A kind of a scanner – works with pulsed laser beams
- Reflected pulses permits for positioning
- Detection and definition of position in relation to other objects (road markings, construction zones, passers-by, vehicles, obstacles)
- Lidar also detects road markings under wet conditions

ROAD MARKING REQUIREMENTS FOR ASSISTANCE SYSTEMS LEVELS 2 - 4

DETECTION BY HUMAN EYE
EN1436



DETECTION BY SENSORS
NO DEFINITION

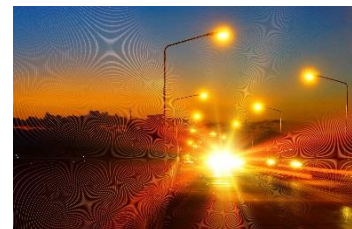


CHALLENGES FOR SENSORS LEVELS 2 - 4



Potholes, cracks,
repairs, phantom
markings,
wheel ruts

Low sun, glare, temporary detours,
driving constrictions



Snow, ice, rain,
mist, spray, black ice

POTTERS & MOBILEYE STUDY (2016)

LEVELS 2 - 4

- ▶ “Sweet spot” between 9 and 12 m
- ▶ Camera systems require contrast
- ▶ Increased retroreflection leads to improved perception
- ▶ White road markings more easy to detect than yellow
- ▶ Wider road markings (10 cm vs. 15 cm) significantly better
- ▶ Dramatic decline in the detection of road markings under wet conditions



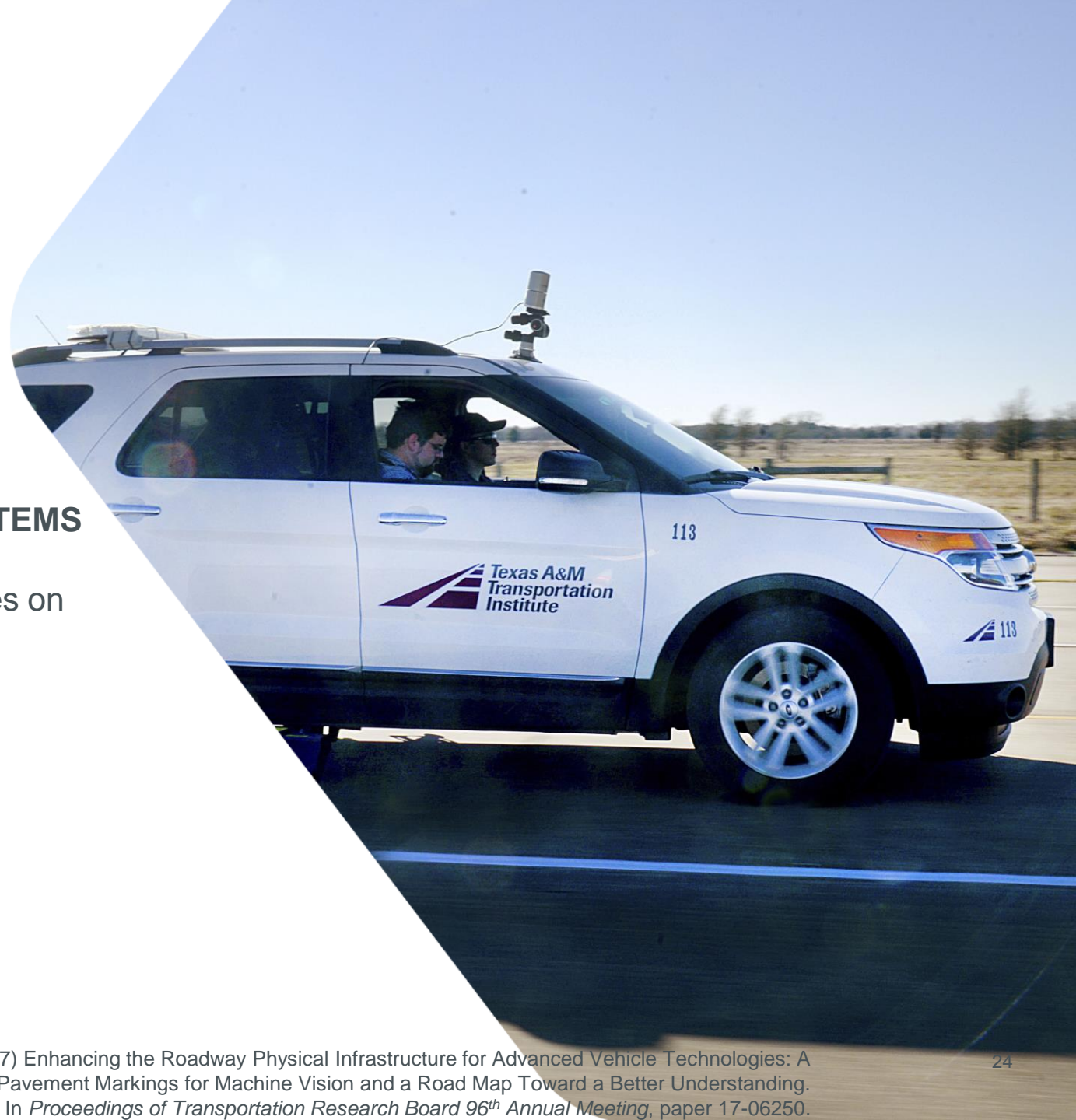
LEVELS 2 - 4

Paul Carlson

Texas A&M University Transportation Institute

PAVEMENT MARKINGS FOR MACHINE VISION SYSTEMS

Impacts of Connected Vehicles and Automated Vehicles on
State and Local Transportation Agencies



DATA COLLECTION SETUP LEVELS 2 - 4

LIDAR



Road Marking Contrast
and Retroreflectivity

HD video-
camera

ADAS
cameras



KEY FINDINGS IN CARLSON'S STUDY LEVELS 2 - 4

Nighttime dry / wet

- ▶ Need minimum R_L of 50 mcd/m²/lx (without glare)
- ▶ Very reliable detection

Daytime dry / wet

- ▶ Need luminance contrast of at least 2:1
- ▶ But preferably closer to 3:1

Wider longitudinal road markings

- ▶ Current ADAS camera capability – not significant
- ▶ Next generation camera capability - promising



RECOMMENDATIONS AND WISHLIST LEVELS 2 - 4

- Maintain road markings at a higher standard
- Eliminate “Bott’s Dots”
- Maintain crisp edges
- Modify 10-30 gap on lane markings
- Improve national uniformity
 - Exit and entrance ramps
 - Intersections
- One standard contrast marking pattern



STATE PRACTICE IN VIRGINIA LEVELS 2 – 4



ROADWAY FACELIFT - CALIFORNIA
LEVELS 2 - 4

LIVE
WASHINGTON

- Update of standards
- Change from 10 cm to 15 cm
- Clearly visible road markings for humans and autonomous cars

SQUAWKalley

MALCOLM DOUGHERTY
CA DEPT. OF TRANSPORTATION DIRECTOR

**CALIFORNIA MODIFYING ROADS
FOR SELF-DRIVING CARS**

 **CNBC**

CONCLUSIONS
LEVELS 2 - 4

Road safety through
road markings

in the future –
and today!



HEUTE



ZUKUNFT

SAFETY

IMPORTANCE OF ROAD MARKINGS TODAY

AT NIGHT DRIVERS FIXATE ON THE MARKINGS

- ▶ Retroreflectivity more important than luminance for all drivers
- ▶ Particularly important in adverse driving conditions
- ▶ Specially needed for elderly drivers
- ▶ Positive impression (and increased safety) with clear markings

Quelle: Underwood, G.; Chapman, P.; Brocklehurst, N.; Underwood, J.; Crundall, D. (2003). Visual attention while driving: sequences of eye fixations made by experienced and novice drivers. *Ergonomics*, 46(6), 629-646.



IMPORTANCE OF ROAD MARKINGS TODAY

DEMOGRAPHIC CHANGE

- ▶ Europe's population is ageing
- ▶ 2020 about 25% of drivers will be over 65 years
- ▶ Reduced reaction times and visual abilities

In need of clear and visible guidance



IMPORTANCE OF ROAD MARKINGS TODAY

+ INCREASED RETROREFLECTION
+ INCREASED VISIBILITY
+ MORE SAFETY

INCREASED RETROREFLECTION

- Up to 20% fewer crashes at curves with high R_L
- Up to 23% decrease in accidents (single vehicle, between intersection) with 100 mcd/m²/lx increase in retroreflectivity

WITH **SOLIDPLUS**

WIDER LINE = LESS CRASHES

- 15 cm wide edge lines = less crashes
- Up to 30-38% reduction in accidents

Sources:

Zwahlen, H.; Schnell, T. (1999). Visibility of road markings as a function of age, retroreflectivity under low-beam and high-beam illumination at night. *Transport. Res. Rec. J. Transport. Res. Board*, 1692, 152-163.

Żakowska, L. (1995). The effect of environmental and design parameters on subjective road safety – a case study in Poland. *Safety Sci.*, 19(2), 227-234.

Carlson, P.; Park, E.; Kang, D. (2013). Investigation of longitudinal pavement marking retroreflectivity and safety. *Transport. Res. Rec. J. Transport. Res. Board*, , 2337, 59-66.

Park, E. S.; Carlson, P. J.; Porter, R. J.; Andersen, C. K. (2012). Safety effects of wider edge lines on rural, two-lane highways. *Accid. Anal. Prev.*, 48, 317-325





MARKING THE WAY TOWARDS A SAFER FUTURE

An ERF Position Paper on how Road Markings can make our road safer



150 mm minimum width

x **150** mcd/m²/lx^(*)

= Minimum standard for road markings

(*) in dry conditions; 35 mcd/m²/lx in wet and rainy conditions.

THANK YOU FOR YOUR ATTENTION!

harald.mosboeck@swarco.com



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