INTERTRAFFIC
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Driving Innovation: Road Infrastructure Solutions for Seamless Autonomous Mobility

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International Road Federation
Fédération Routière Internationale
Federación Internacional de Carreteras

Introduction

- Modern vehicles rely on machine vision to assist the driver and help to move into higher levels of automation
- Lane Departure Warning (LDW) and Emergengy Lane Keep Systems (ELKS) depend on the detection of the pavement marking
- International studies point to the crucial relationship between these Advanced Driver Assistance Systems (ADAS) and pavement marking visibility and quality

UN/ECE Regulation 130 Type Approval

Lane Departure Warning System (LDWS)
Emergency Lane Keeping System (ELKS)

Test procedure and limitations

- on straight, flat and dry roads
- under visibility conditions that allow safe driving at the required test speed
- with the markings being in good condition and of a material conforming to the standard for visible markings
- in all illumination conditions without blinding of the sensors (e.g. sunlight) and with activated passing-beam headlamps if necessary
- in absence of weather conditions affecting the visibility of lane markings (e.g. no fog).

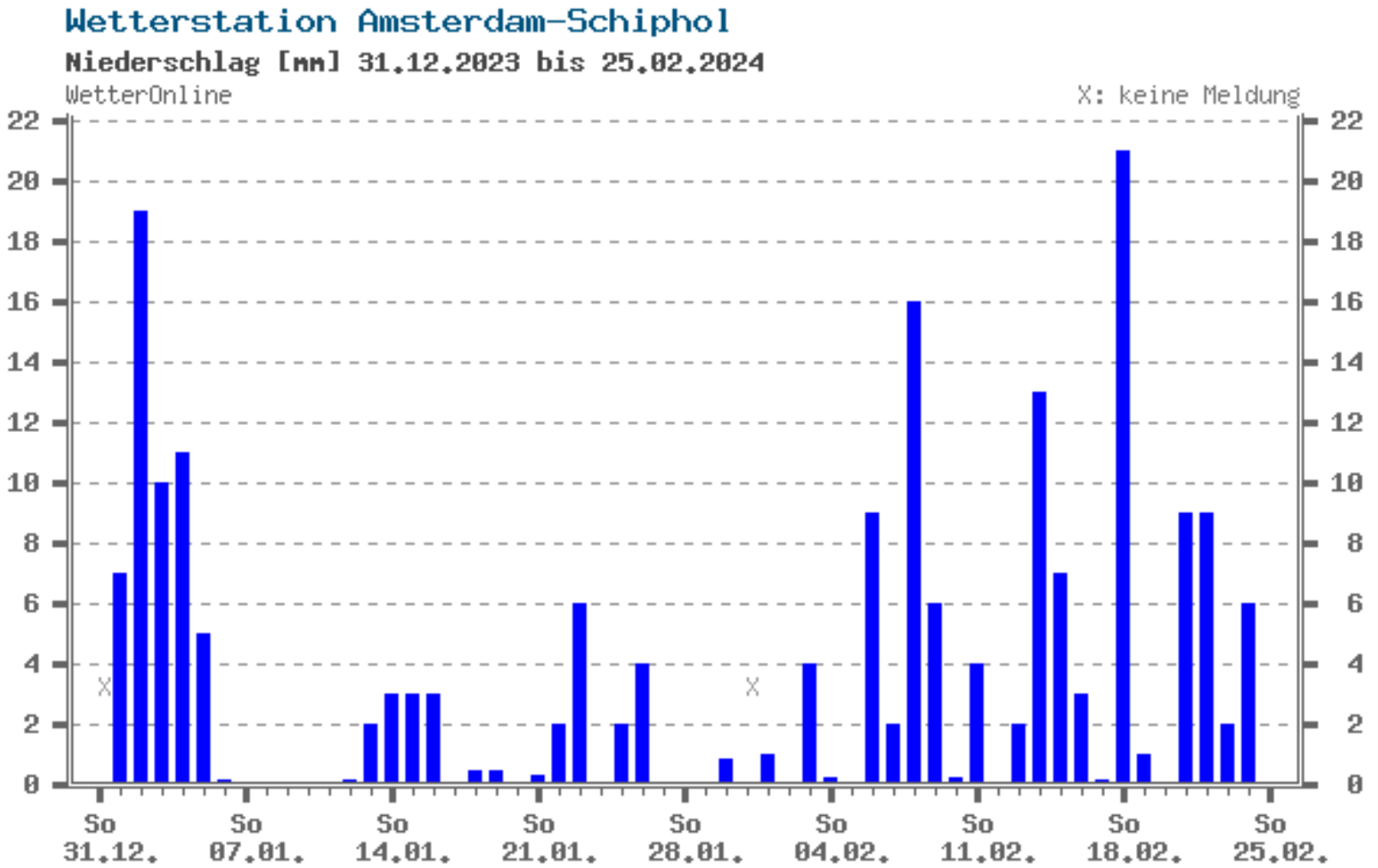
Source: UN/ECE Regulation No. 130
EU Regulation 2021/646

Operational Design Domain (ODD): Dry

How realistic is dry in the Netherlands ?

First 56 days in 2024

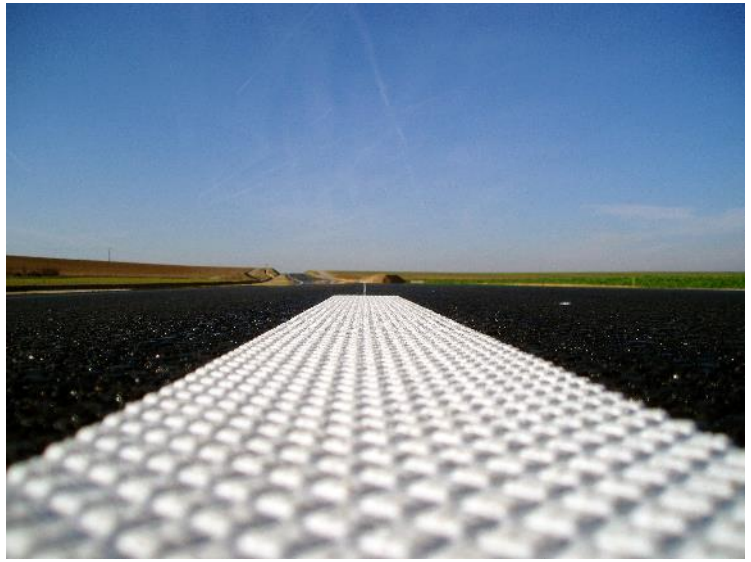
- 17 days dry
- 11 days wet < 2 mm (2 l/m²)
- 28 days rain > 2 mm
- EN 1436 rain rate 2 mm/h



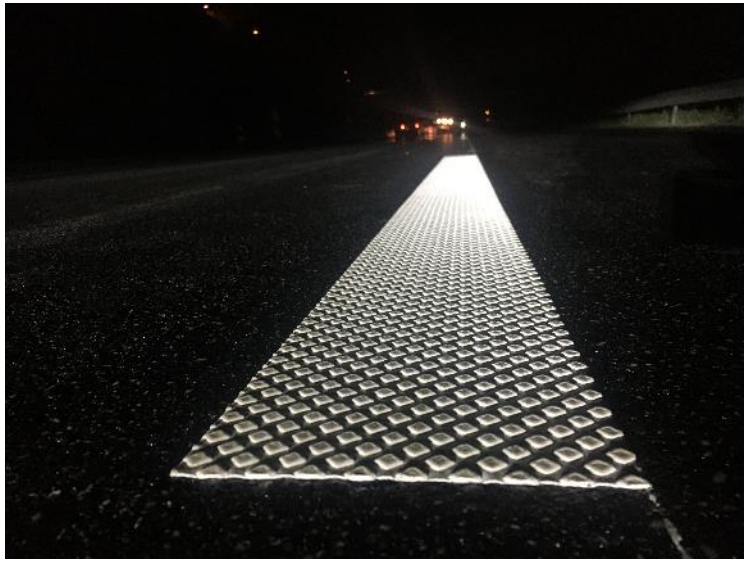
Source: www.WetterOnline.de

‚The Standard for Visible Markings‘

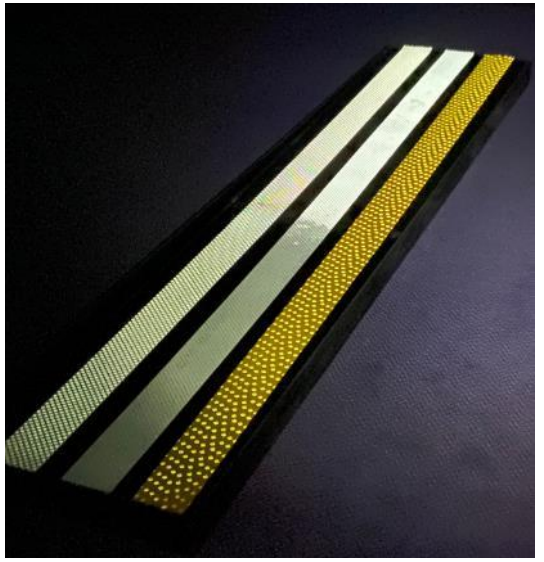
EN 1436: Road marking materials
Road marking performance for road users and test methods



Daytime Luminance Qd
Luminance Qd (diffuse)



Nighttime dry
Retroreflected Luminance (Headlamp)

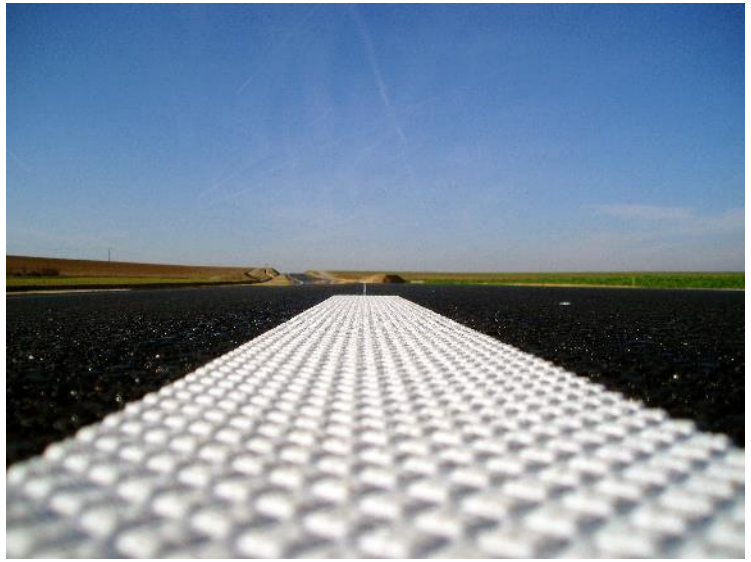


Nighttime wet / rain

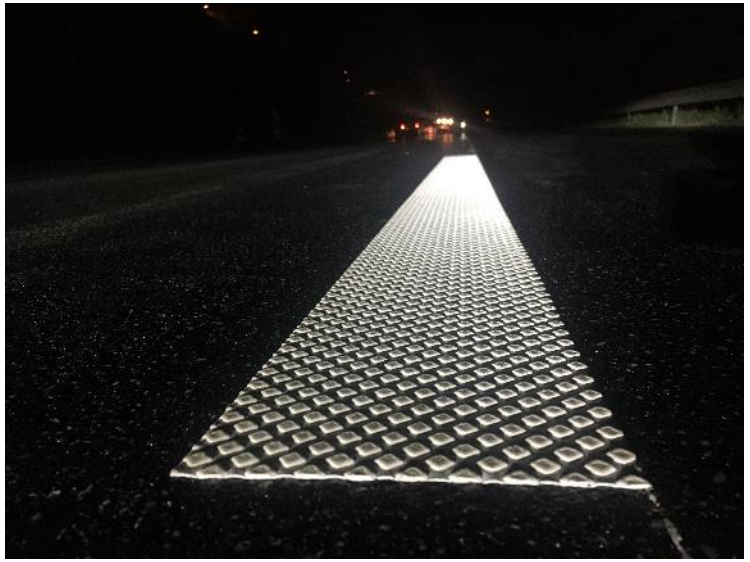
Source: EN 1436:2018 Road marking performance for road users and test methods

European Road Federation ERF

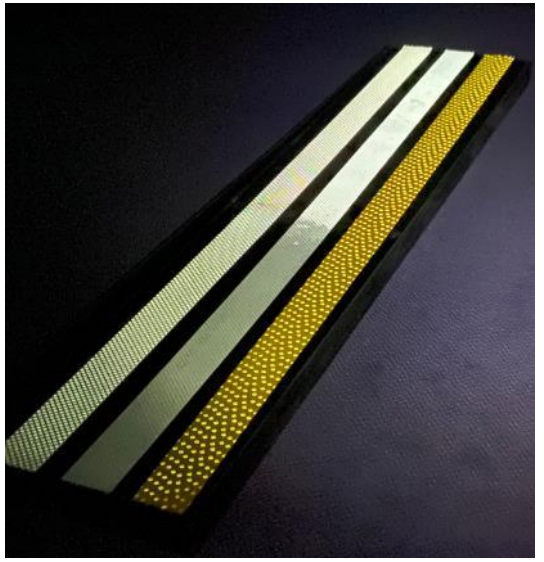
Road Markings technical recommendations to adapt CAVs



Contrast 3:1 (better 4:1)
Width > 15 cm



Nighttime dry
> 150 mcd/lx/m²

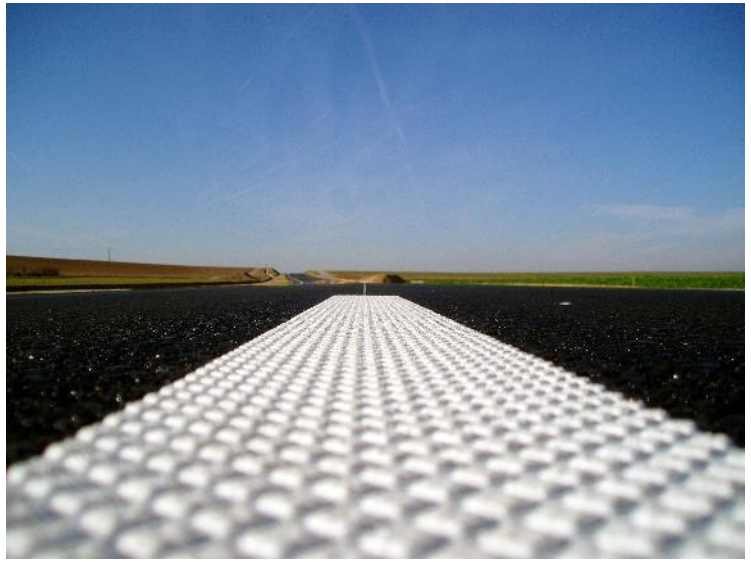


Nighttime wet / rain
> 35 mcd/lx/m²

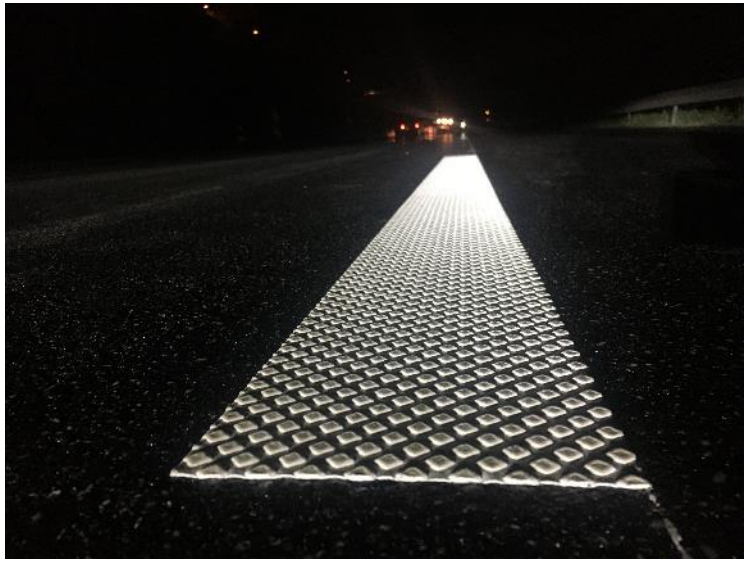
Source: ERF technical recommendations to adapt CAVs - Road Markings, 2019

All Weather Technology

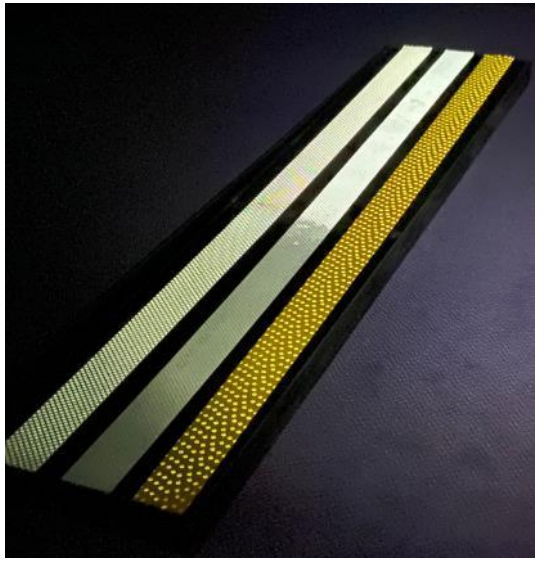
Superior Rain performance with 3M All Weather Technology



Contrast > 4:1



Nighttime dry
> 500 mcd/lx/m²

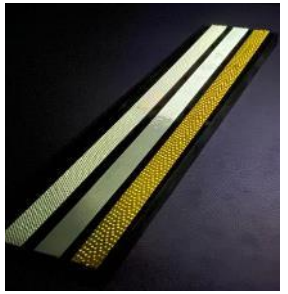


Nighttime wet / rain
> 250 mcd/lx/m²

Source: Specification for 3M™ Stamark™ High Performance All Weather Tape Series 380AW

3M All Weather Technology

Road Markings technical recommendations to adapt CAVs



3M All Weather
Visibility Distance 100 m
Preview Time 3 s

ERF Minimum
Visibility Distance 50 m
Preview Time 1.5 s

60 year old driver, low beam headlamp, 30 cm edge line, 4 m lane width, 120 km/h

Source: COST 331 Requirements for horizontal road markings, 1999

Machine vs. Human Vision (CEN TC 226 / WG2)

Correlation between current visibility characteristics and machine vision

- Literature research reveals that there is a wide range of recommended minimum values from different studies and their experimental conditions.
- In the state of actual knowledge, it is not possible to provide a recommendation for a threshold minimum based on the current EN 1436 geometry.
- Even very good road marking quality does not guarantee sufficient contrast with the surrounding road, e. g. in heavy rain, snow and glare, especially caused by an opposite low sun or opposing night traffic on a wet road.
- Both the human driver and automated vehicles would benefit from road markings with improved detectability in adverse conditions as e. g. rain.

Source: CEN TC 226 / WG2 Road Marking for Connected Automated Driving Project RMCAD, Task 100, 2023

TU Delft

Road test with different light and weather conditions
Three cars (model year 2023) and four lane markings

- Research confirmed that optical lane marking detectability is important as state-of-the-art LKA systems in vehicles still rely mostly on cameras for detection
- To facilitate a working LKA system, lane markings should be detectable in adverse circumstances where the driver might fail to detect the lane markings
- Higher values of wet retroreflectivity (RW) of lane markings increase performance of LKA systems
- Improving retroreflection and contrast leads to a higher detection rate. This contributes to traffic safety and might prevent accidents

Source: Impact of improved lane marking properties on the performance of Lane Keeping Assistance systems in varying circumstances, TU Delft 2023

TU Delft

Study confirms limitations of LDW and ELK Systems as considered in type approval

- Lane markings are 3,3 times more likely to be detected in dry circumstances compared to wet: '*Test on dry asphalt' – 'in absence of weather conditions affecting the visibility of lane markings'*

- Driving towards a light source, either the sun or oncoming traffic decreases detection likelihood 4,5 to 5 times compared to a daytime situation driving away from the sun: *'in all illumination conditions without blinding of the sensors (e.g. direct blinding due to sunlight)'*

- All new lane markings performed significantly better than old white paint lane marking. Detection likelihood increased with 2,1 to 4,3 times: *'with the markings being in good condition'*

Source: Impact of improved lane marking properties on the performance of Lane Keeping Assistance systems in varying circumstances, TU Delft 2023

Swarco Windtunnel Tests

What can Cameras see?
Lidar vs. Cameras

Rule of Thumb:

If you can’t see it, the camera can’t see it either…

but…if you can see it, the camera doesn’t necessarily see it

Source: Burghardt TE, Popp R, Helmreich B, et al. Visibility of various road markings for machine vision. Case Studies in Construction Materials 2021; 15: e00579

Lidar Sensor vs. Camera

Lidar is active (own lightsource)

- Does not suffer from typical camera issues such as low light, glare, shadows
- Always good contrast when pavement marking is retroreflective to IR light
- Higher Retroreflection improves Lidar detection
- Not sensitive to glare sources (sun, oncoming traffic, street lighting)
- Detection in wetness and rain still depending on wet retroreflectivity of the PM

Source: Burghardt TE, Popp R, Helmreich B, et al. Visibility of various road markings for machine vision. Case Studies in Construction Materials 2021; 15: e00579

Operational Design Domain (ODD): Wet & Rain

Make LDW and ELK useful in adverse weather, extend ODD for Level 3 vehicles

Class RW 0, no wet performance

Class RW2 – RW4 (varying rain-rate)

Source: Analysis of nighttime driving behavior at different retro-reflective longitudinal pavement markings, Rainvision Project, DG Move, 2015

Conclusions

- Improving retroreflection and contrast leads to a higher detection rate. This contributes to traffic safety and might prevent accidents
- PM retroreflection in wet and rain is essential for both camera and Lidar detection
- Lidar and camera complement each other and may increase the ODD for automated driving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