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3M™ Connected Roads

Optimized Infrastructure for Mixed Fleet, Machine and Human Vision Systems

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Transportation Safety Division

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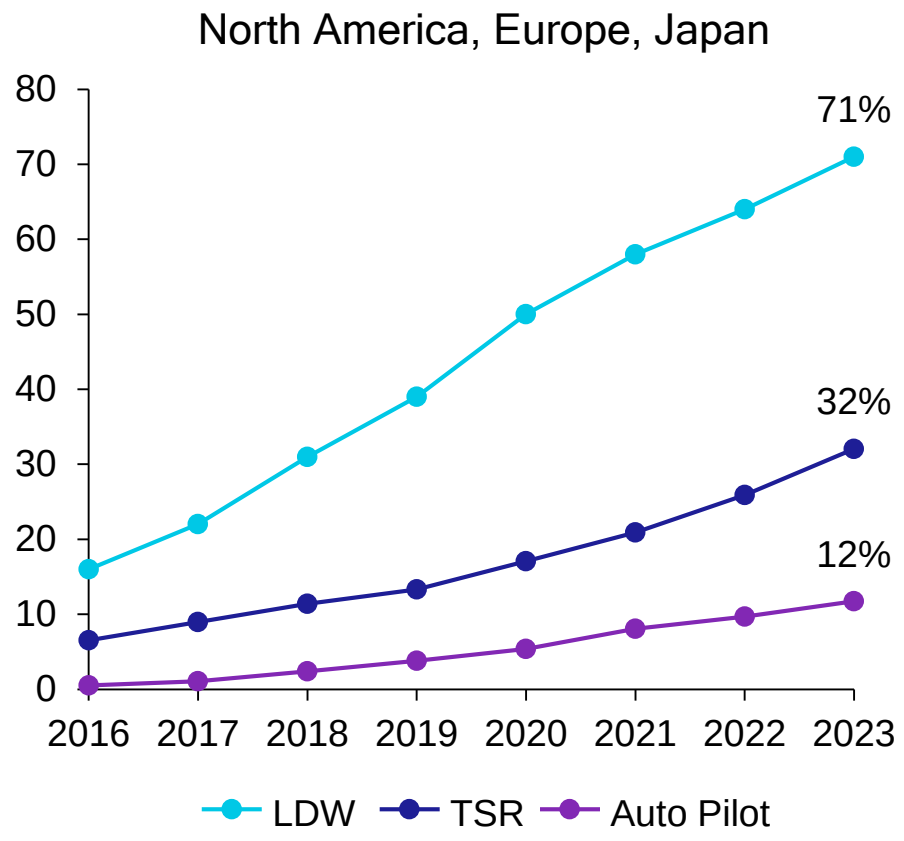
Lane Departure Warning / Lane Keeping

By 2023, Lane Departure Warning in 71% of all new cars

New car penetration of ADAS features is increasing with LDW reaching 71% in 2023



Experts report that effective LDW/LKA* can reduce accidents and save money

"LDW would reduce rates of crashes of all severities **by 11%** and crashes with injuries **by 21%** in the United States"[1]

"LKA would reduce the number of fatalities **by 15.2%** and injuries **by 8.9%** in the EU25 if fully deployed"[2]

"At 11% market penetration, LDW would reduce monetary and non-monetary loses in Japan **by 21.9%**"[3]

* LDW: Lane Departure Warning
LKA: Lane Keep Assist

Source: ADAS Production Forecast Database, March 2018, IHS Markit

1 – Cicchino, 2018, Journal of Safety Research
2 – Wilmink et al., 2008, eIMPACT Consortium
3 – Miyoshi, 2017, Intl Transportation Electrification Conf.

Machine Vision Systems Build a Lane Model

Visibility of lane markings

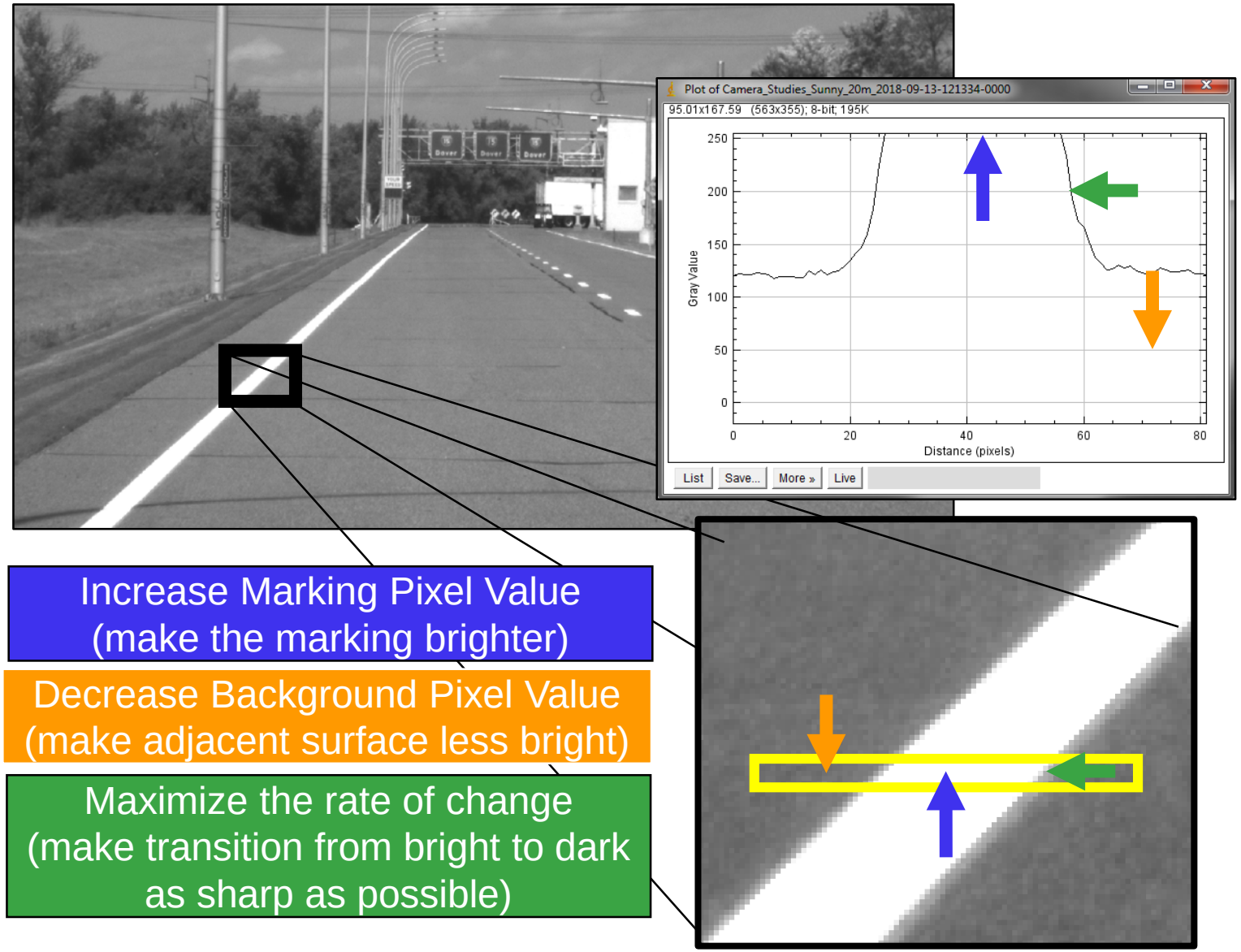
- In general, improving the visibility of lane markings for humans makes them more visible to machine vision systems
  - Minimally need presence of marking on the road – consistency of implementation is helpful
  - Lane markings often include optical elements intended to provide visibility at night
  - Contrast markings help visibility on light colored pavement
  - Lane marking dimensions and performance are not uniform

- Automated vehicles rely on the sharp contrast between the luminance of the pavement marking and the luminance of its immediate background to detect the pavement marking[1].
- Poor pavement markings, adverse weather conditions and glare interfere with continuous automated vehicle operation and require special consideration

- Consistent dimensions and geometries are helpful and appropriate metrics ensure markings are effective

1 -*A review of recent advances in lane detection and departure warning system.* **Narote, Sandipann P, et al.** s.l. : Elsevier, January 2018, Pattern Recognition, Vol. 73, pp. 216-234.

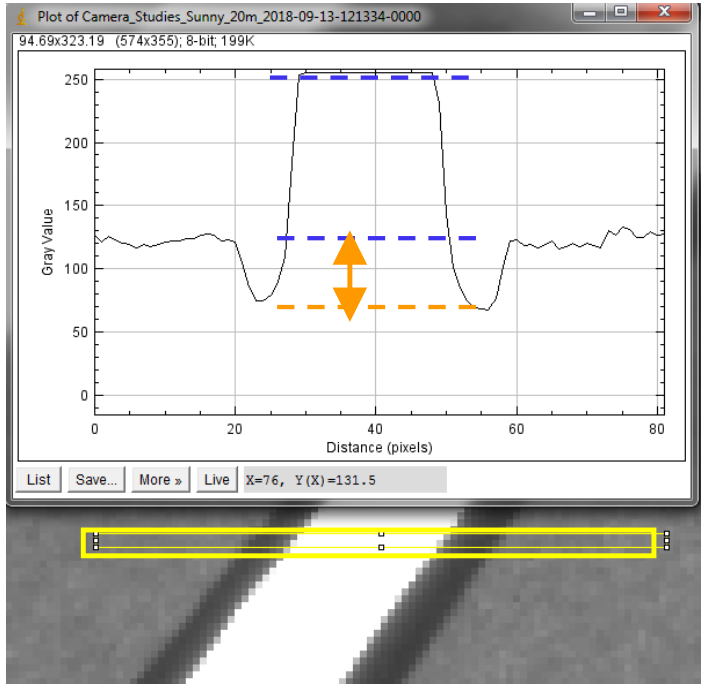
Maximize Contrast



Increase Marking Pixel Value
(make the marking brighter)

Decrease Background Pixel Value
(make adjacent surface less bright)

Maximize the rate of change
(make transition from bright to dark as sharp as possible)



Consistent black edge

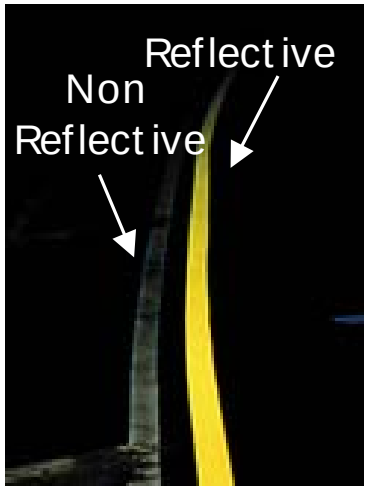
Black markings on the right and left of the main lane marking increase contrast and enhance the perception of the lane marking

Extending the operational domain in night and rain

- Nighttime: only 25% of driving occurs at night, 50% of traffic deaths happen at night[1]
- Rainfall: increases the relative risk of crash and injury rates by 71% and 49% respectively[2]
- Markings need to be retroreflective and provide sufficient signal-to-noise to be seen
- Continuous wet retroreflective to provide sufficient signal-to-noise at night in the rain
- Look ahead distance depends on headlight brightness and the retroreflectivty of the markings

Poor Daytime Road Presence

Non Reflective vs. Reflective



Non Wet Reflective vs. Wet Reflective Markings

Source: [1] *The Most Dangerous Time to Drive,* National Safety Council, 2018
[2] Effects of Adverse Weather on Traffic Crashes, Transportation Research Board, 2008

Visibility and Detection in Rain

Dry Daytime Conditions

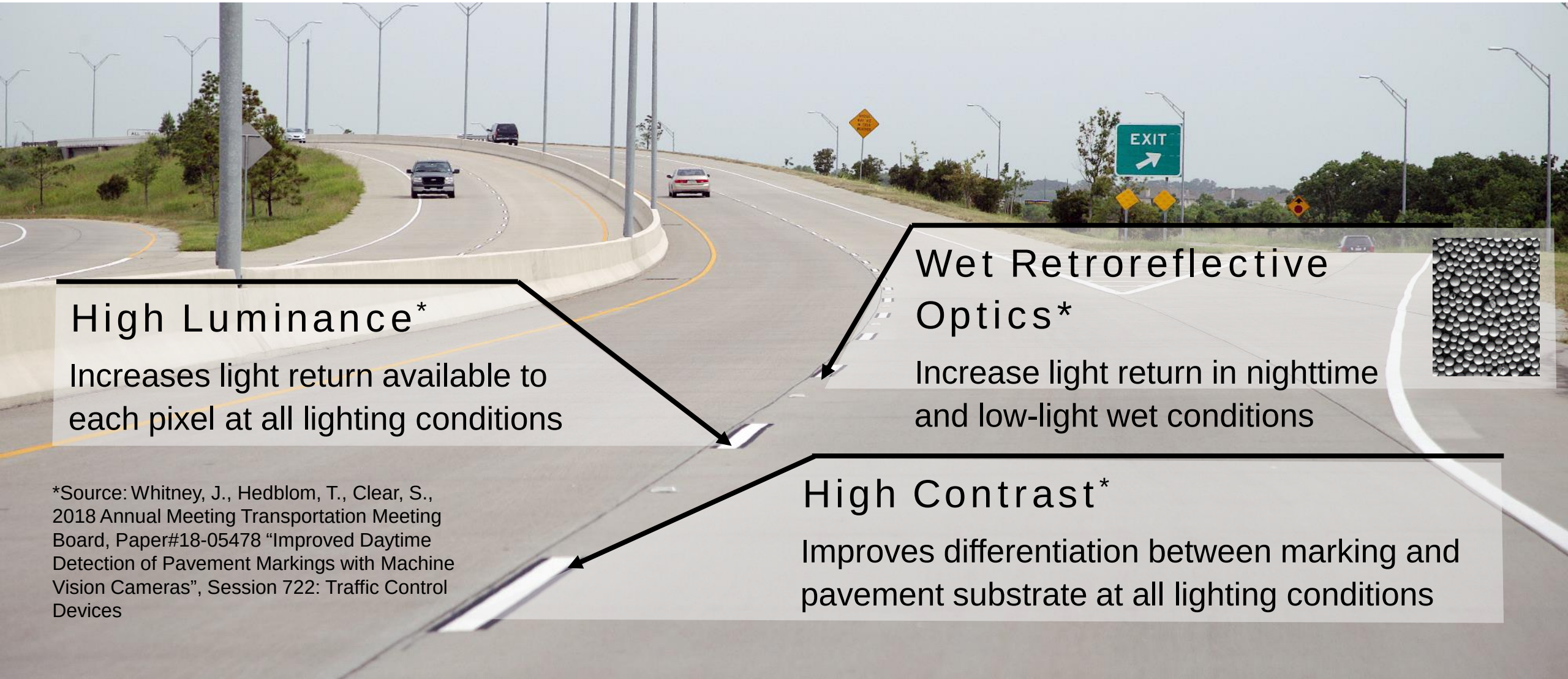
Dry Nighttime Conditions

Wet Nighttime Conditions

Yellow Line = Optimized for wet retroreflectivity

White Line & Arrow = Not optimized for wet retroreflectivity

Key Characteristics of Pavement Markings Likely to Improve Detection by Machine Vision Cameras



High Luminance*

Increases light return available to each pixel at all lighting conditions

Wet Retroreflective Optics*

Increase light return in nighttime and low-light wet conditions

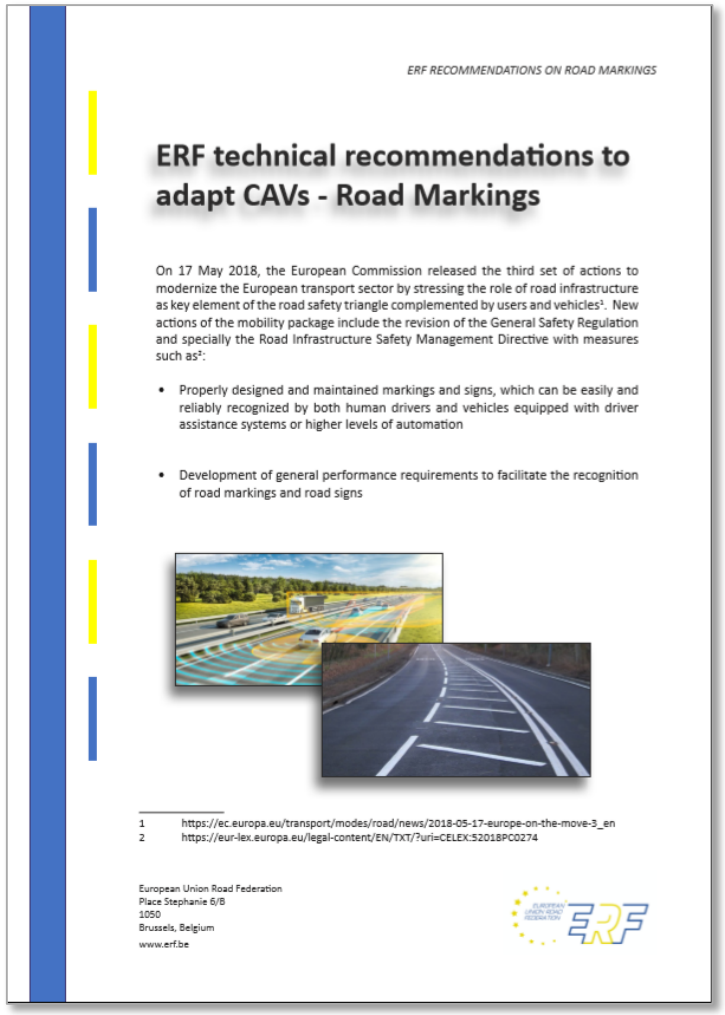
High Contrast*

Improves differentiation between marking and pavement substrate at all lighting conditions

*Source: Whitney, J., Hedblom, T., Clear, S., 2018 Annual Meeting Transportation Meeting Board, Paper#18-05478 “Improved Daytime Detection of Pavement Markings with Machine Vision Cameras”, Session 722: Traffic Control Devices

Lane Marking Performance

European technical recommendations[1]



ERF RECOMMENDATIONS ON ROAD MARKINGS

ERF technical recommendations to adapt CAVs - Road Markings

On 17 May 2018, the European Commission released the third set of actions to modernize the European transport sector by stressing the role of road infrastructure as key element of the road safety triangle complemented by users and vehicles[1]. New actions of the mobility package include the revision of the General Safety Regulation and specially the Road Infrastructure Safety Management Directive with measures such as[2]:

- Properly designed and maintained markings and signs, which can be easily and reliably recognized by both human drivers and vehicles equipped with driver assistance systems or higher levels of automation
- Development of general performance requirements to facilitate the recognition of road markings and road signs

1 https://ec.europa.eu/transport/modes/road/news/2018-05-17-europe-on-the-move-3_en
2 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018PC0274

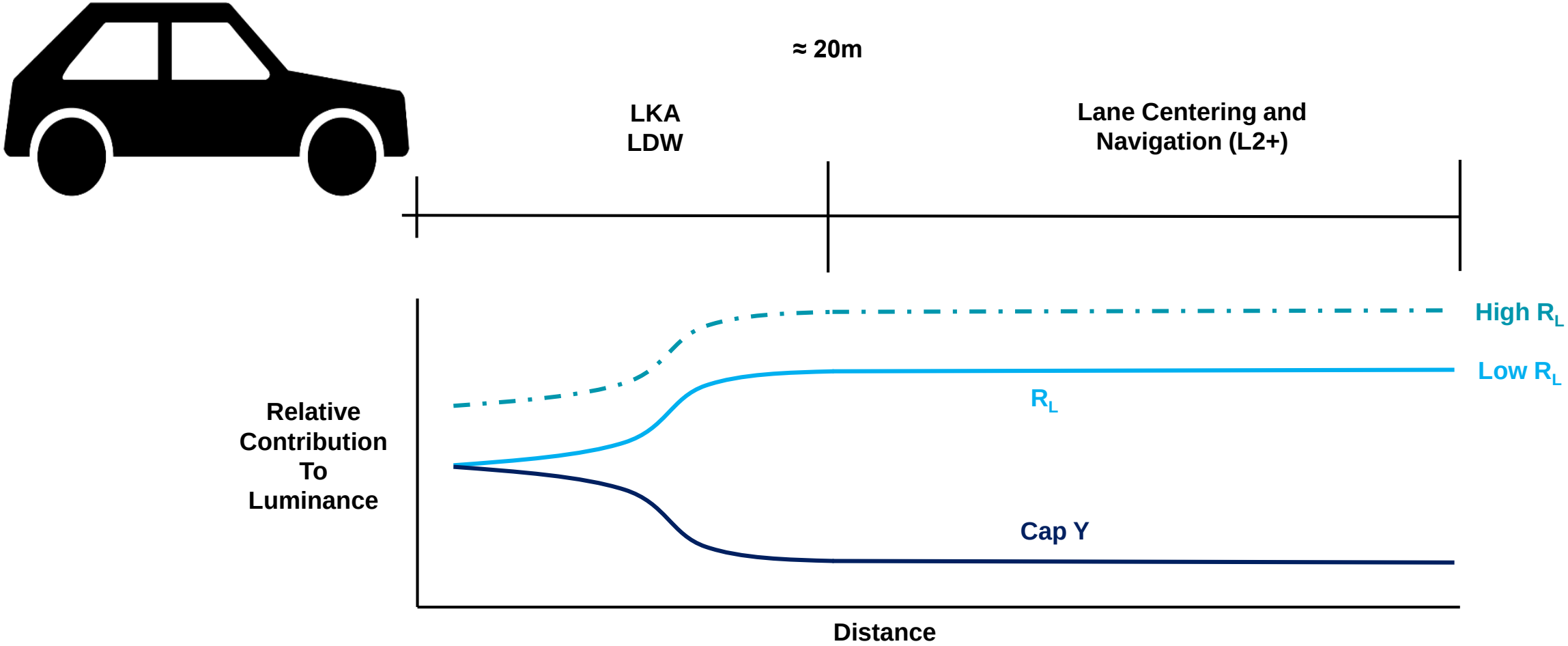
European Union Road Federation
Place Stephanie 6/B
1050
Brussels, Belgium
www.erf.be

"The European Road Federation strongly supports the road safety approach of the European Commission.

- Based on the analysis of research taking into consideration both vehicles equipped with driver assistance systems and human requirements, the ERF proposes the establishment of an intervention and maintenance policy as follows:"
  - **Night visibility** should never drop below 150 mcd/lx/m2
  - **Rainy conditions** should never drop below 35 mcd/lx/m2 (recent studies in US and EU also point to even higher levels)
  - Ensure a sufficiently **high contrast ratio** between marking and pavement. While a contrast ratio of 3:1 appears sufficient, increased reliability can be achieved with a 4:1 ratio, mitigating possible false readings caused by glare and other critical conditions.

1 – ERF website: http://erf.be/wp-content/uploads/2019/03/ERF-Recommendations-on-Road-Markings_FINAL.pdf

Nighttime: Both R_L & Cap Y plus reflective optics and distance



Pike, A., Clear, S., Hedblom, T., Barrette, T., "Effects of the Wet Retroreflectivity and Luminance of Pavement Markings on Lane Departure Warning in Nighttime Continuous Rain with and without Glare Sources," Unpublished results, submitted to WCX SAE World Congress April 2019

Aktan, F., Schnell, T., "*An Interactive Computer Model to Determine the Nighttime Visibility of Normal and UV Activated Pavement Markings Under Normal and UV Headlamp Illumination*", Proceedings of the CIE Istanbul 2001 International Lighting Congress, 12-14 September, Istanbul, Turkey, 2001

Studying the Effects of the Wet Retroreflectivity and Luminance of Pavement Markings on LDW in Nighttime Continuous Rain

Table 1. Pavement marking properties based on ASTM standards.

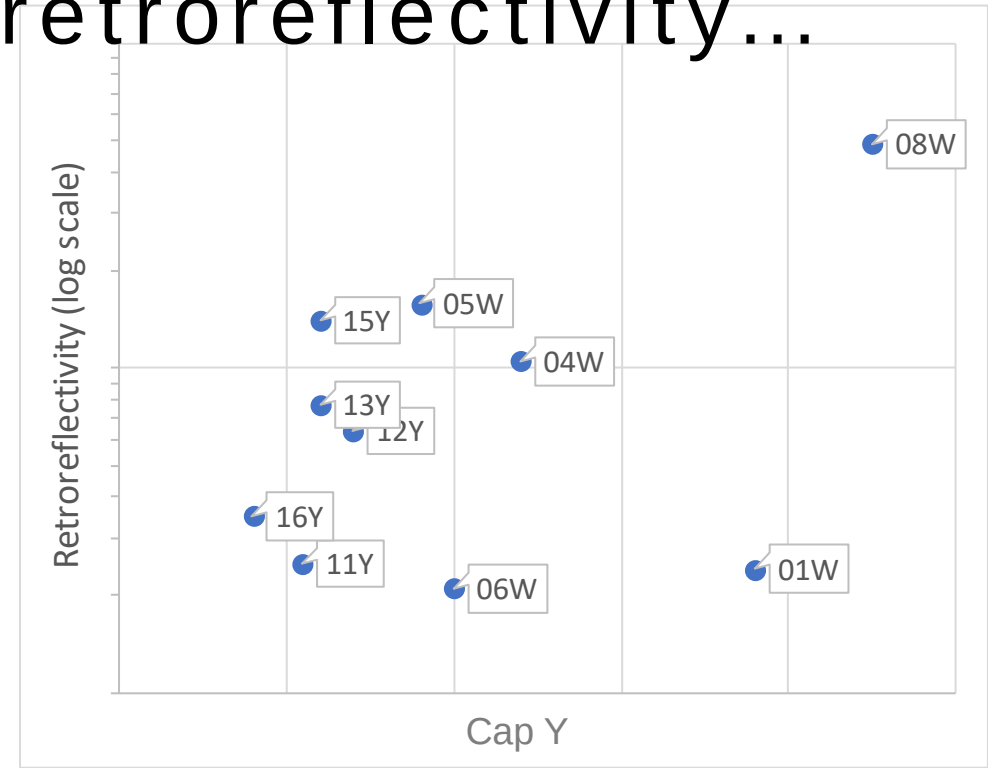
Marking	Cap Y	Qd (mcd/m²/lx)	Continuous R_L (mcd/m²/lx)
01W	58	248	24
04W	44	190	105
05W	38	170	158
06W	40	200	21
08W	65	220	490
11Y	31	150	25
12Y	34	148	64
13Y	32	139	77
15Y	32	145	140
16Y	28	128	35

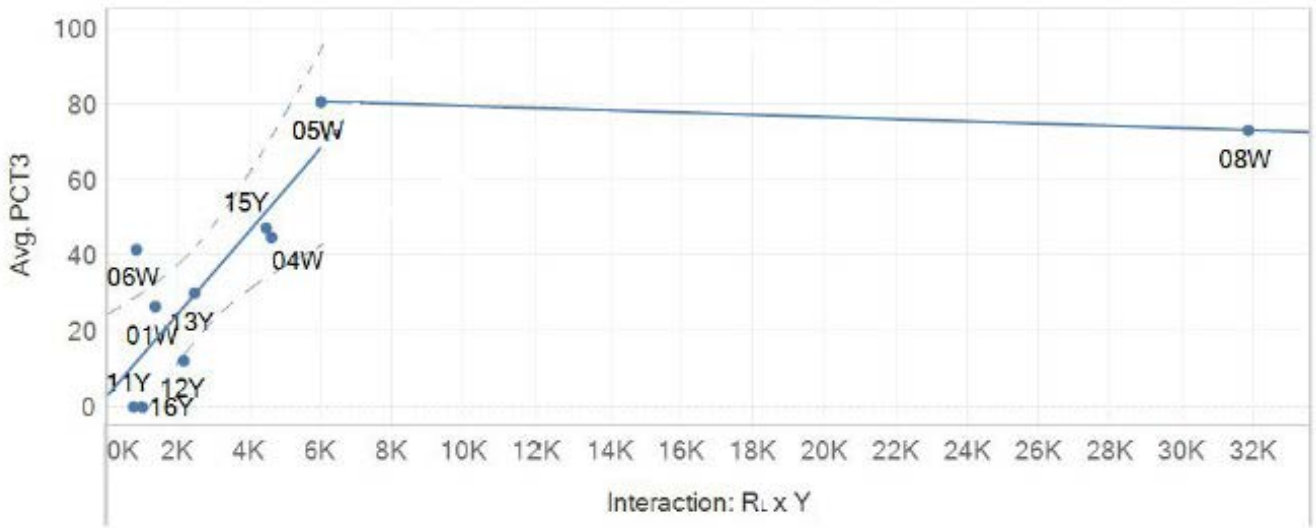
- Study conducted on 3M's private track in Cottage Grove, MN

- 360 feet of 4-inch wide aluminum panels placed at 10-foot intervals; both yellows and white samples were evaluated
- Aluminum panel were constructed of preformed tape designed for specific optical properties, positioned in rain tunnel
- Rainfall averaged 1.5 in/h over the markings
- Data collection via a Mobileye 5 Series ADAS unit mounted on a Ford Explorer, LDW confidence ratings of 0-3 were extracted and recorded

Pike, A.M., Clear, S., Barrette, T., Hedblom, T., and Whitney, J. "Effects of the Wet Retroreflectivity and Luminance of Pavement Markings on Lane Departure Warning in Nighttime Continuous Rain with and without Glare Sources, accepted to SAE Journal, 2019 WCX SAE World Congress, Detroit, 2019.

Confidence is a function of luminance and retroreflectivity…





1) Different parameters matter in different conditions (e.g. day/night, dry/wet)
2) Different parameters matter for different functionality (e.g. LKA, navigation)
3) PM performance needs to be maintained over time to enable optimal MV system functionality

Pike, A.M., Clear, S., Barrette, T., Hedblom, T., and Whitney, J. "Effects of the Wet Retroreflectivity and Luminance of Pavement Markings on Lane Departure Warning in Nighttime Continuous Rain with and without Glare Sources, accepted to SAE Journal, 2019 WCX SAE World Congress, Detroit, 2019.

Fundamental Metrics

When

Who

	Day (Cap Y %)	Night – Dry	Night – Wet
Human	Cap Y	R_L	R_{L-W}
LKA, LDW	Cap Y*	Cap Y R_L	Cap Y R_{L-W}
L2+	Cap Y*	R_L	R_{L-W}
LIDAR	R_L		R_{L-W}

- Cap Y (%) - ASTM E 1349
- R_L (mcd/m^2/lux) - ASTM E 1710
- R_{L-W} (mcd/m^2/lux) - ASTM E 2832
- All levels specified are **minimum retained** values

*Multiple Cap Ys may need to be specified for the marking for varying pavement marking backgrounds

Thank You