Supporting scientific literature

1. Retroreflectivity of road markings should not on any road drop below:

- 150 mcd/m²/lx under dry conditions
- 50 mcd/m²/lx under wet conditions
- 35 mcd/m²/lx under rainy conditions

Gibbons, R. B.; Williams, B.; Cottrell, B. (2012). The Refinement of Drivers' Visibility Needs During Wet Night Conditions. *Transportation Research Record: Journal of the Transportation Research Board,* 2272, 113–120; DOI 10.3141/2272-13.

> Analysis based on preview distances, concluding: "This study recommends a minimum retroreflectivity of **150 mcd/m²/lx** for white and yellow pavement markings **in both dry and wet night time** conditions."

Parker, N.; Meja, M. (2003). Evaluation of performance of permanent pavement markings. *Transportation Research Record: Journal of the Transportation Research Board*, 1824, 123–132; DOI 10.3141/1824-14.

> Closed-circuit field testing in the United States, concluding: "The results suggested that the threshold value of an acceptable versus unacceptable level of retroreflectivity appeared to be between 80 and 130 mcd/m²/lux for (…) drivers younger than 55 and **between 120 and 165 mcd/m²/lux for drivers older than 55**."

Horberry, T., Anderson, J., Regan, M. A. (2006). The possible safety benefits of enhanced road markings: a driving simulator evaluation. *Transportation Research Part F: Traffic Psychology and Behaviour*, *9*(1), 77–87; DOI 10.1016/j.trf.2005.09.002.

> Driving simulator testing of horizontal road markings with high and low retroreflectivity, concluding: "The study found **consistently superior results for the enhanced markings** in comparison to the standard markings for both the **objective driving performance and the workload/subjective data**."

Diamandouros, K.; Gatscha, M. (2016). Rainvision: The Impact of Road Markings on Driver Behaviour–Wet Night Visibility. *Transportation Research Procedia*, 14, 4344–4353; DOI 10.1016/j.trpro.2016.05.356.

> Closed-circuit field testing in Austria, with enhanced road marking having retroreflectivity under dry conditions 407–572 mcd/m²/ lx and under wet conditions 43–112 mcd/m²/lx, concluding: "the presence of **enhanced road markings did significantly increase driver comfort, especially for older drivers**."

Pashkevich, A.; Burghardt, T. E.; Żakowska, L.; Nowak, M.; Koterbicki, M.; Piegza, M. (2017). Highly Retroreflective Horizontal Road Markings: Drivers' Perception. In *Proceedings of International Conference on Traffic Development, Logistics and Sustainable Transport*; Opatija, Croatia, 1-2 June 2017: 277–287.

> Questionnaires assessment after test application of enhanced road marking, concluding: "58-75% of respondents reported noticing markings with retroreflectivity higher than the standard (...). Over **80% of respondents felt that road safety during nighttime driving would increase if horizontal markings had higher retroreflectivity**."

Hadi, M., Sinha, P. (2011). Effect of Pavement Marking Retroreflectivity on the Performance of Vision-Based Lane Departure Warning Systems. *Journal of Intelligent Transportation Systems*, 15(1), 42–51; DOI 10.1080/15472450.2011.544587.

Evaluation of vision-based lane-departure warning systems (LDWS), concluding: "**improving the retroreflectivity** (…) **improves the performance of LDWS** (…) performance improves significantly with the use of enhanced types of pavement markings that have high visibility during rain."

2. The width of horizontal road markings should not be less than 15 cm

Park, E. S.; Carlson, P. J.; Porter, R. J.; Andersen, C. K. (2012). Safety effects of wider edge lines on rural, two-lane highways. *Accident Analysis and Prevention*, 48, 317–325; DOI: 10.1016/j.aap.2012.01.028.

Statistical analysis of accidents in the United States, concluding: "This study provides detailed evidence to suggest that **wider edge lines are effective in reducing crashes on rural, two lane highways, especially with regard to relevant target crashes such as single vehicle crashes** (…). The safety effects of wider edge lines were consistently positive and statistically significant using data from three states."

State of California (2017). Implementation of six-inch wide traffic lines and discontinuing use of non-reflective raised pavement markers. Department of Transportation memorandum, 19 July 2017. Available at:
http://www.dot.ca.gov/trafficops/policy/memo_6-in-wide-traffic-lines_051917.pdf.

3. The unification of markings across various countries is needed to improve the reliability of machine vision and universality of automated vehicles, but also to improve mobility and safety amongst human drivers

Shinar, D.; Dewar, R. E.; Summala, H.; Zakowska, L. (2003). Traffic sign symbol comprehension: a cross-cultural study. *Ergonomics*, 46 (15), 1549–1565; DOI 10.1080/0014013032000121615.

Comprehension of road signs varies widely between cultures and countries. The study concluded: "signs that conform to good ergonomic design principles are more likely to be fully comprehended than signs that violate these requirements. **Signage should be standardized across countries as much as possible, so that the number of signs unique to a country will be kept to a minimum**."

Räsänen, M., Horberry, T. (2006). Harmonisation of road signs and markings on the Trans-European Road Network to improve road safety in the EU. Presented at *2006 European Transport Conference*; Strasbourg, France, 18-20 September 2006.

Analysis of European road network signage, which concluded: "**Harmonisation** of road signing and markings among EU countries **may prevent** (…) estimated **5,000 annual road deaths** on the TERN."

O'Connor, G., Evans, C., Cairney, P. (2018). *Harmonisation of pavement markings and national pavement marking specification.* Austroads Research Report No. AP-R578-18.

In Australia, steps are taken to make line width 150 mm, retroreflectivity above 150 mcd/m²/lx, and signalisation uniform across the country.

4. Maintenance of a sufficiently high contrast ratio between the marking and pavement is needed to mitigate possible false readings caused by glare. While a contrast ratio of 3:1 appears sufficient, better results can be achieved with a 4:1 ratio

Theeuwes, J.; Alferdinck, J. W.; Perel, M. (2002). Relation between glare and driving performance. *Human Factors*, 44 (1), 95–107; DOI 10.1518/0018720024494775.

Even though the glare studies concentrated on glare caused by a light source and detection of pedestrians, the same principles do apply to visibility of road markings: "The results show that **the relatively low glare source caused a significant drop in detecting simulated pedestrians** along the roadside and made participants drive significantly slower on dark and winding roads."

Hagita, K.; Mori, K. (2011). Analysis of the influence of sun glare on traffic accidents in Japan. *Journal of the Eastern Asia Society for Transportation Studies*, 9, 1775–1785; DOI 10.11175/easts.9.1775.

Analysis of accidents frequency in Japan, concluding: "**when the sun is in a position that tends to blind drivers, traffic accidents tend to be more frequent**".

Mitra, S. (2014). Sun glare and road safety: An empirical investigation of intersection crashes. *Safety Science*, 70, 246–254; DOI 10.1016/j.ssci.2014.06.005.

Analysis of accidents frequency in the United States, concluding: "**odds of glare crash occurrence are higher** in east and west bound compared to north and south bound directions."

Snowden, R. J., Stimpson, N., Ruddle, R. A. (1998). Speed perception fogs up as visibility drops. *Nature*, 392 (6675), 450; DOI 10.1038/33049.

Glare might cause effects similar to driving in fog, where due to a "**perceptual quirk**: it appears that drivers think they are driving far more slowly than they actually are in foggy conditions, and therefore increase their speed."

Winter, J., Fotios, S., Völker, S. (2018). The effects of glare and inhomogeneous visual fields on contrast detection in the context of driving. *Lighting Research & Technology*, 50 (4), 537–551; DOI 10.1177/1477153516672719.

A laboratory evaluation of capability to detect an object under constant luminance in the presence and absence of glare, concluding: "**Glare increased the contrast needed for detection of the foveal target** (…). For peripheral targets, contrast threshold was also reduced by the presence of extraneous light at a non-target location and this effect was increased in the presence of glare."

Whitney J., Hedblom T., Clear S. (2018). Improved Daytime Detection of Pavement Markings with Machine Vision Cameras. Presented at *Transport Research Board committee AHB50 Standing Committee on Traffic Control Devices*. Washington DC, United States, 7-11 January 2018

Pavement marking tapes with high values of Y and black contrast exhibit plateau behaviour over a wide range of illuminations conditions that result in Weber contracts above a threshold level (**~ 4 for the camera specifications used in this study**), and a linear dependence on Weber contrast for Weber contrast below that threshold.