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TECHNIQUES IMPLEMENTED BY ROAD SIGNAL ANALYSIS AT NATIONAL LEVEL

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Abstract

Road markings and traffic signs are integral components of road infrastructure and represent essential road safety elements. Their presence can either positively or negatively influence road users, thereby increasing or decreasing overall road safety, depending on their condition. Road markings and signs play a particularly important role in conditions of reduced visibility. In order for road markings and traffic signs to be visible in such conditions, they must be retroreflective. Retroreflection is the ability of an object to reflect light back towards a light source along the same axis from which it originates [1]. Therefore, in order to ensure adequate levels of reflectivity, both road markings and traffic signs should be checked periodically with metrologically certified measuring instruments.

The aim of this paper is to highlight the methods used to analyse the variation in quality parameters on retroreflective films applied to the front of road signs by measuring the retroreflection coefficient RA.

For longitudinal road markings, the parameter used to determine their quality is the retroreflected luminance coefficient RL, which is determined continuously.

In this study, we looked at how the results were affected by weather and traffic conditions on road signs.

Keywords: traffic safety, road markings, fixed vertical signage, retroreflection

1. INTRODUCTION

In Romanian road networks, traffic signs and pavement markings are fundamental safety devices that support driver guidance, warning, and regulation - especially at night and during reduced visibility (rain, fog, glare). Under these conditions, visibility depends strongly on retroreflection, i.e., the optical ability of a material to return incident headlamp light back toward the driver. The practical implication recognized across road-safety practice is that retroreflective performance is not only a design requirement but also a maintenance-critical attribute because degraded retroreflection can reduce detection distance and legibility, particularly on higher-speed roads.

At a national level, Romanian technical regulations and road authority documentation also support implementation and harmonization. The national road administrator C.N.A.I.R. (National Romanian Roads Administration Agency) publishes technical norms and guidance documents that address road equipment and traffic engineering practice, typically aligning requirements and terminology with SR/SR EN standards.

To ensure adequate levels of retroreflection, both road markings and vertical signs should be checked regularly. Several methods of quality control are used in practice, such as typical visual inspections and various measurement methods. Overall, damaged and/or insufficiently retroreflective road markings and traffic signs have been shown to be an influential factor in road accidents in low visibility conditions. Quality control of road markings and fixed vertical traffic signs, in accordance with SR EN 1436 and SR EN 12899-1, includes various tests that can be performed statically or dynamically, such as the retroreflected luminance coefficient RL, chromatic measurements, SRT value, retroreflection coefficient RA, resistance to weather phenomena and other tests to which traffic signs, etc. are subjected.

Since most decisions in traffic are based on visual cues and perceptions, from a safety perspective, the most important tests are those related to visibility, i.e. the retroreflection of road markings and signs.

Retroreflective road signs and pavement markings are fundamental components of road infrastructure, providing critical visual information to drivers, particularly under nighttime and reduced-visibility conditions. The effectiveness of these elements depends on their ability to return vehicle headlamp light toward the driver, a property quantified using the coefficient of retroreflection RA for traffic signs and the coefficient of retroreflected luminance RL for longitudinal pavement markings. A substantial body of research has investigated the performance of these parameters, focusing on degradation mechanisms, measurement methodologies, and their implications for road safety.

Previous studies on traffic signs demonstrate that retroreflective performance deteriorates over time and is influenced by multiple factors, including material type, colour, age, orientation, and surrounding environment. Field investigations reveal that degradation patterns vary significantly across retroreflective sheeting technologies and colours, indicating that service life and maintenance needs cannot be reliably predicted based on age alone [2]. More recent research shows that field-measured RA values can be effectively modelled using machine-learning approaches, enabling prediction of future performance and supporting condition-based maintenance and asset management strategies [3].

In addition to long-term material ageing, several studies highlight the importance of external and operational factors in influencing measured retroreflectivity. Weather conditions, surface contamination, dirt accumulation, and measurement circumstances can introduce short-term variability in observed RA values, emphasizing the need for standardized measurement procedures and careful documentation of field conditions during in-service inspections [4]. Foundational visibility research further confirms that inadequate sign retroreflectivity leads to reduced nighttime detection distances and legibility, reinforcing RA as a critical safety-related performance indicator [5]. Complementary synthesis reports stress the importance of standardized measurement geometries, calibrated instruments, and periodic inspections to ensure consistent evaluation of retroreflective sheeting performance throughout the service life of traffic signs [6].

For longitudinal pavement markings, the literature consistently demonstrates a strong relationship between retroreflective performance and driver guidance, particularly under nighttime and adverse visibility conditions. Safety-oriented studies establish that insufficient RL values are associated with reduced visibility and increased crash risk, highlighting the importance of maintaining minimum retroreflectivity thresholds [7]. Long-term and large-scale field investigations show that pavement marking retroreflectivity degrades progressively due to traffic wear, weathering, and environmental exposure, with degradation rates varying according to marking material, application technique, and traffic intensity [8,9]. Recent research emphasizes the role of material composition, particularly paint characteristics and glass bead properties, in determining both initial and in-service RL performance [10]. Furthermore, studies integrating construction quality inspection and advanced analytical techniques demonstrate that variability in measured RL values is often linked to differences in installation practices and inspection conditions, underscoring the importance of standardized testing methods and systematic monitoring [11].

Broader synthesis and review studies provide additional context by linking retroreflectivity assessment to regulatory frameworks, maintenance practices, and emerging analytical approaches. Research summarized by the Federal Highway Administration underscores the importance of systematic inspection programs based on defined retroreflectivity thresholds for ensuring nighttime sign visibility [12]. Complementary FHWA synthesis work on pavement markings identifies retroreflectivity as a key performance parameter for lane recognition while also noting substantial variability in measured RL values due to differences in materials, traffic exposure, and maintenance strategies [13]. Methodological reviews further highlight the necessity of standardized measurement geometries, calibrated instruments, and consistent field procedures when assessing in-service retroreflective performance of road signs. More recent modelling studies integrate pavement condition indicators and traffic characteristics with retroreflectivity data, demonstrating that traffic intensity and surface condition are significant predictors of retroreflective performance and supporting a more holistic, data-driven approach to road asset management [14].

Overall, the reviewed literature indicates that while the retroreflective performance of road signs and pavement markings is governed by material properties and long-term ageing processes, measured values of RA and RL are also sensitive to environmental and operational conditions. This highlights the importance of periodic, standardized measurements using calibrated instruments and points to the need for further investigation into how weather and traffic conditions influence observed retroreflectivity under real-world operating environments, thereby motivating the present study.

The data was collected following a three-year verification period (2021-2023), through measurements taken in six stages, at approximately six-month intervals, on 26 sections located on 7 national roads, totalling 1,448 kilometres, and monitoring more than 12,000 vertical road signs in each stage.

The results of the measurements provide many aspects that may be important both from a statistical point of view and in terms of accumulating knowledge that can be used in decision-making regarding the proper management of road safety.

2. METHODOLOGY

Both road markings and signs must be tested periodically to ensure that they meet the parameters declared by the manufacturer and/or the requirements of the regulations in force. The quality of road signage is assessed through several tests, so that for retro-reflective films applied to the front of road signs, the retro-reflection coefficient RA is measured, and for road markings, the retro-reflected luminance coefficient RL is measured.

2.1 The process of measuring road signs

Road signs are checked in accordance with SR EN 12899-1, and the main quality parameter considered is the RA retroreflection coefficient. In order to comply with the requirements of the aforementioned standard, a ZRS 6060 certified mobile retroreflectometer was used, which measures at an illumination angle (β) = $+5^0$ and at 3 observation angles (α): 0.2^0, 0.33^0, 2^0. It has the ability to automatically recognise the measured colour and store the GPS coordinates of a measurement. The result taken into account for each measurement is the arithmetic mean of 5 determinations for each colour. Before performing the measurement procedure, calibration is performed using the front plate, which has a factory-measured calibration standard and is always mounted on the equipment. After completing the calibration procedure, the calibration results are displayed on the screen and are then confirmed by pressing the "Accept" button. After calibration, the front plate is mounted in the measuring position. The equipment is placed perpendicular to the product to be measured, and the measure button is pressed to trigger a measurement. In the main window, the measurement values will be displayed next to each viewing angle. Measurements can be taken individually or by calculating the average of several readings. After the measurements have been taken, the collected data is downloaded to a computer in the form of a database with the extension .zsdf, which is then opened with the data mapping and analysis software [15].

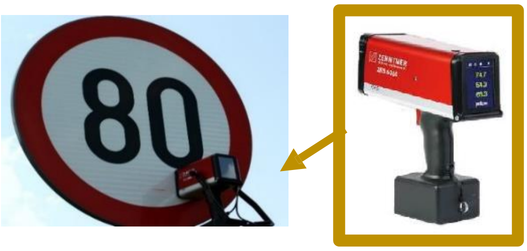

Figure. 1 Retro-reflectometer ZRS 6060

2.2 The process of measuring road markings

The parameter monitored in terms of road marking quality is the retroreflected luminance coefficient, denoted RL, expressed in $mcd.m^{-2}\cdot lx^{-1}$ (night-time visibility). This night-time visibility refers to the ability of the marking to reflect the light projected by car headlights to the driver.

The marking subject to measurement must meet the following requirements: it must be clean, dry and free of salt traces.

The equipment used is called ECODYN 3 and is a mobile retroreflectometer mounted on a car, which makes it possible to continuously measure the retroreflection of road markings over tens or even hundreds of kilometres in a single pass without the use of special signalling, thus reducing the risk of accidents.

The results obtained provide information to the road manager, helping them to schedule campaigns to replace inadequate road markings, check the quality of the products used to make the markings and monitor their deterioration over time. In this way, a substantial contribution can be made to improving road safety and the cost-effective replacement of road markings and at the appropriate time.

Measurements are taken in the direction of traffic and are in accordance with the geometric parameters defined in European standard SR EN 1436, i.e. 1.24° in relation to the road surface for transmission and 2.29° for reception (i.e. a divergence angle of 1.05° between transmission and reception).

These geometric parameters simulate the driver's visibility of the marking at a distance of 30 m when illuminated by the headlights of a car (standard) located at 0.65 m and the observer (eyes) at a height of 1.20 m.

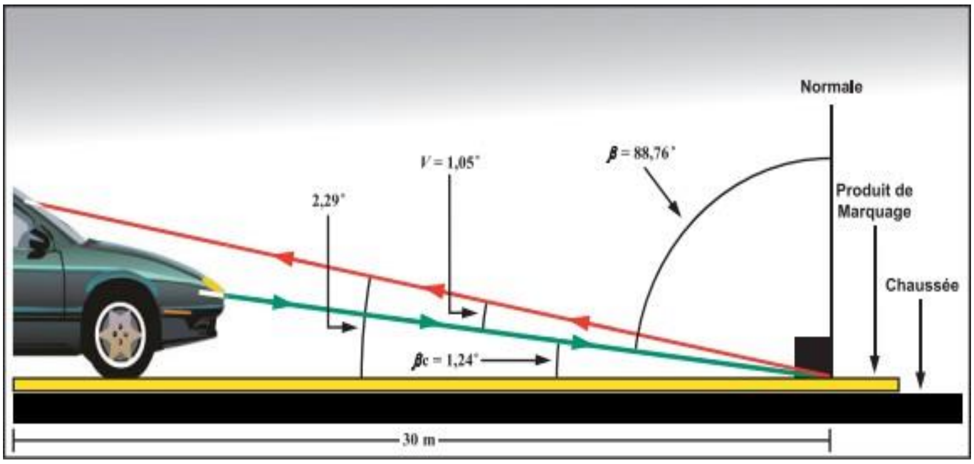

Figure. 2 Graphical representation of the RL measurement geometry

To measure retroreflection, Ecodyn 3 emits pulsating white light through an optical device towards the marking and the road surface at a distance of approximately 6 m. The retroreflected light coming from the marking and the road surface is focused on 32 photodiodes by a second optical device. The detected signals are filtered by separating the retroreflected signals from the marking from the relative ambient light signals.

Ecodyn is equipped with two measuring units/heads on the right and left, symmetrical to the centre line of the vehicle, an electronic unit for transmitting and receiving signals, and a microcomputer for data acquisition and processing.

Data acquisition (readings ≈ every 40 cm) does not depend on the speed of the vehicle. The position of the device relative to the road marking is monitored by the driver using a bar graph located on the vehicle's dashboard. The results are displayed as average values for sections of 100 m and 500 m in length. The measuring range extends from a few mcd/m²·lx to approximately 2,000 mcd/m²·lx.

In addition to visual displays in the form of lists and graphs, the results can be incorporated into a database and presented in the form of route diagrams or maps.

The steps for preparing the measurement session are as follows:
- Install the measuring units outside the vehicle.
- Power the components and the programme.
- Perform static calibration.
- Check the geometry of the measuring heads with the laser pointer.

Measurement session - after the calibration sequences described above, the actual measurement session can begin, during which observations regarding the condition of the mark can be entered.

Acquisition results - the acquired data is presented by the acquisition programme in graphical and tabular form. This data is transferred to a computing unit and can be processed using the equipment software [16].

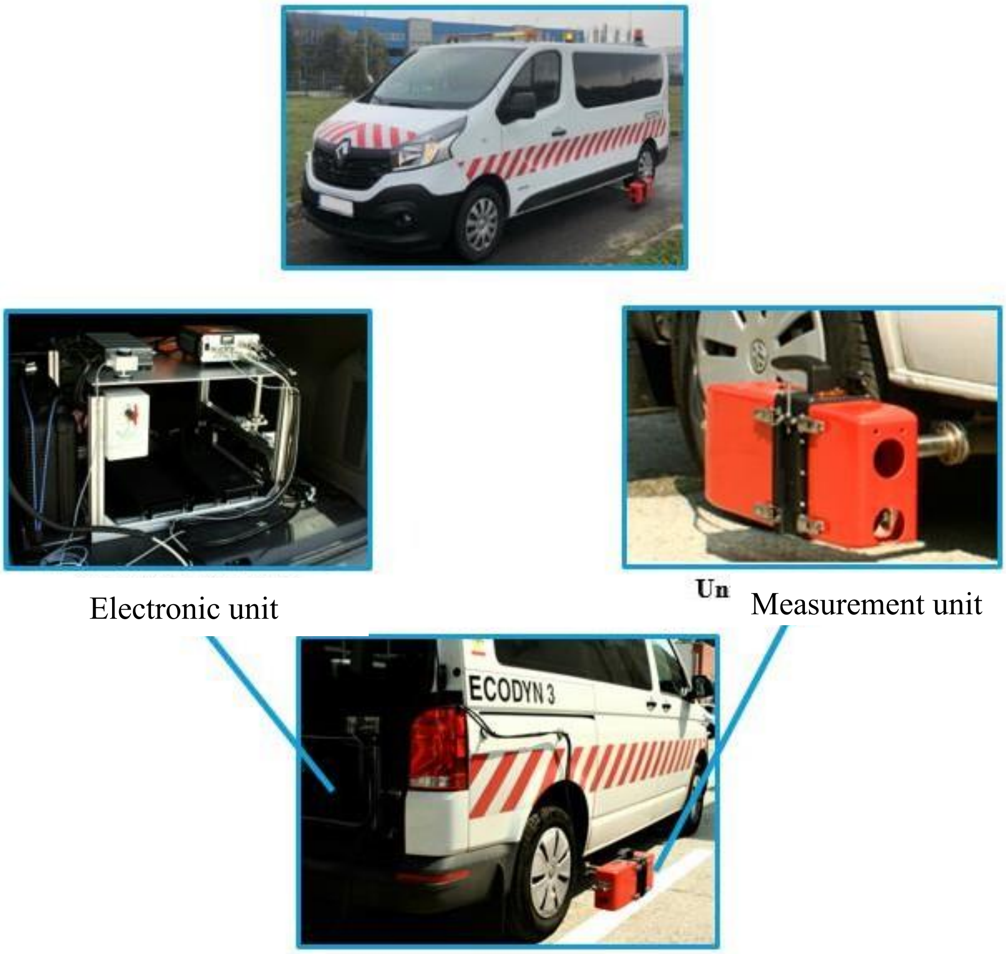

Figure. 3 ECODYN 3 equipment

3. RESULTS

3.1 Climate aspects and factors that can influence the quality and lifespan of road markings

Environmental conditions can have a major influence on the performance of materials used for road marking. Factors that should be considered include: temperature (air and substrate to which it is applied), atmospheric humidity, wind speed, surface moisture at the time of application. Each of the above factors can affect the performance of the marking. Air and substrate temperatures are important because most marking materials require a minimum temperature for drying or curing. Humidity also affects drying and curing times. Wind speed affects drying times, but more importantly, it affects the dispersion of glass beads. Strong winds can prevent a large percentage of the beads from reaching the binder material evenly. The surface moisture of the substrate at the time of application can have a severe effect on the marking material's ability to adhere to the road surface.

Year-round climatic conditions can also affect the long-term performance of road marking materials. Regions with heavy snowfall are often exposed to severe abrasion on road markings due to snow ploughing and the chemical activity of substances used to prevent ice and frost. Intense exposure to ultraviolet rays can also affect the lifespan of both vertical and horizontal road markings.

Next, we will discuss the influence of "stressors" on the quality and durability of vertical traffic signs and road markings.

Climatic factor

Romania's climate is temperate-continental transitional, marked by some oceanic, continental, Scandinavian-Baltic, sub-Mediterranean and Pontic climatic influences. Thus, in Banat and Oltenia, the Mediterranean influence is noticeable, characterised by mild winters and higher rainfall (especially in autumn). In Dobrogea, the Pontic influence is noticeable, with rare but torrential rains.

In the eastern regions of the country, the continental character is more pronounced. In the northern part of the country (Maramureş and Bucovina), the effects of the Scandinavian-Baltic influence are evident, resulting in a wetter and colder climate with frosty winters. In the west of the country, the influence of low-pressure systems generated over the Atlantic is more pronounced, resulting in more moderate temperatures and higher precipitation.

Temperature

Average annual temperatures decrease slightly from south (10°-11°C) to north (8.5°-9°C), a variation due to both latitude and the distribution of the country's relief. The temperature also decreases with increasing altitude (decreasing by 6° for every 1000 m). Average annual maximum temperatures range from 22°C to 24°C in summer and from -3°C to -5°C in winter.

The average annual temperature varies from 11 degrees Celsius in the Danube floodplain to 6 degrees Celsius in Harghita. The average temperature in July varies between 26 degrees Celsius and 18 degrees Celsius, depending on the region. In January, these temperatures range from 0°C (in Băile Herculane or Mangalia) to -6 degrees Celsius (in the depressions).

Precipitation

Precipitation in Romania is moderate, with an average annual rainfall of 637 mm. Average annual precipitation in the plains varies between 400 mm in Dobrogea, 500 mm in the Romanian Plain and up to 600 mm in the Western Plain. Precipitation increases with altitude, reaching 1000–1200 mm/year at altitudes above 1800 m.

Days with ≥ 1.0 mm of precipitation are considered "rainy days".

The average annual number of days with precipitation varies across the country between less than 100 and 200. The fewest such days (<100) are recorded in eastern Dobrogea and central Bărăgan. In the southern plains, the Bârlad Plateau and the western edge of the Arad Plain, the annual number of days with precipitation is 125, and in the Western Plain and Hills, the Transylvanian Plateau, the Subcarpathians and the Getic Piedmont, the Moldavian Subcarpathians and the rest of the Moldavian Plateau, there are up to 150 days. The highest number of days with precipitation, over 190, is recorded in the mountainous area, especially in the northern group of the Eastern Carpathians, on the peaks of the Bihor-Vlădeasa massifs and in the Southern Carpathians. In the intramountainous depressions and in the south-west of the Transylvanian Plateau, the average number of days with precipitation is lower than in the neighbouring areas, totalling between 100 and 120.

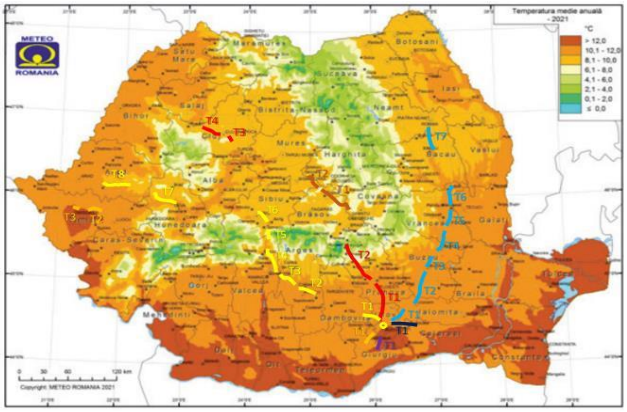

Figure 4. Average annual temperature - 2021

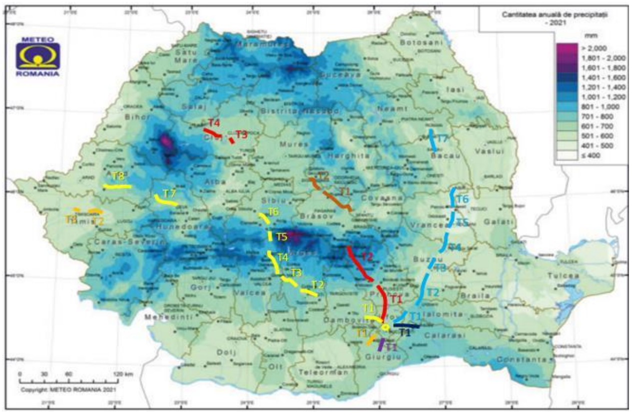

Figure 5. Annual precipitation - 2021

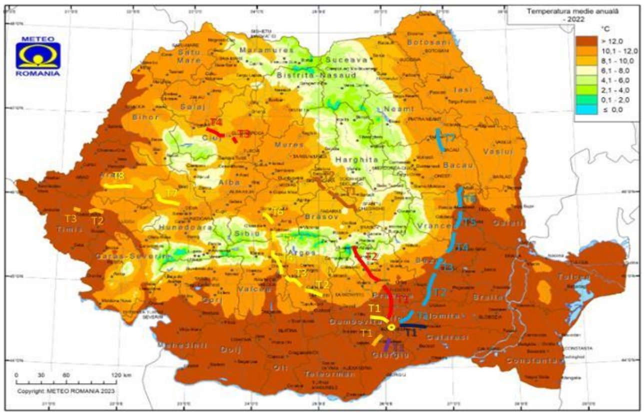

Figure 6. Average annual temperature – 2022

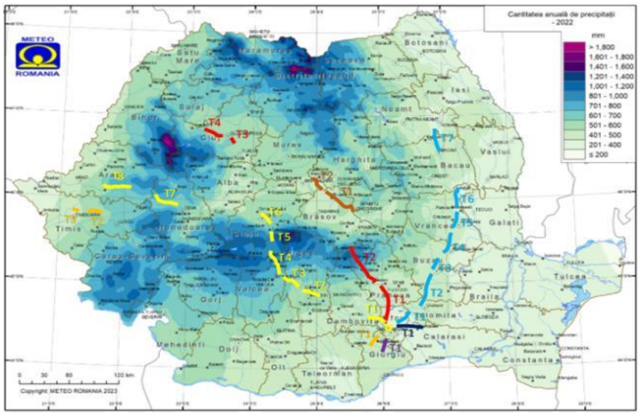

Figure 7. Annual precipitation - 2022

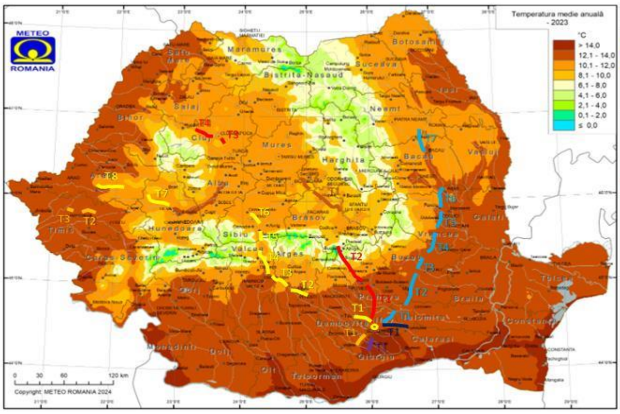

Figure 8. Average annual temperature - 2023

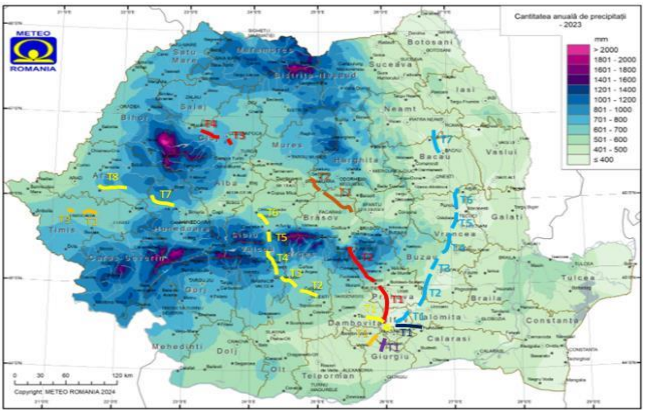

Figure 9. Annual precipitation - 2023

On each of the maps presented in Figures 4 to 9 [17], we have also shown the layout of the measured sections in order to create a suggestive image for the discussions that will follow, regarding vertical road signs and horizontal road markings.

Another factor that can influence the durability of markings is the degree of exposure to solar radiation, which in our country is shown in Figure 10.

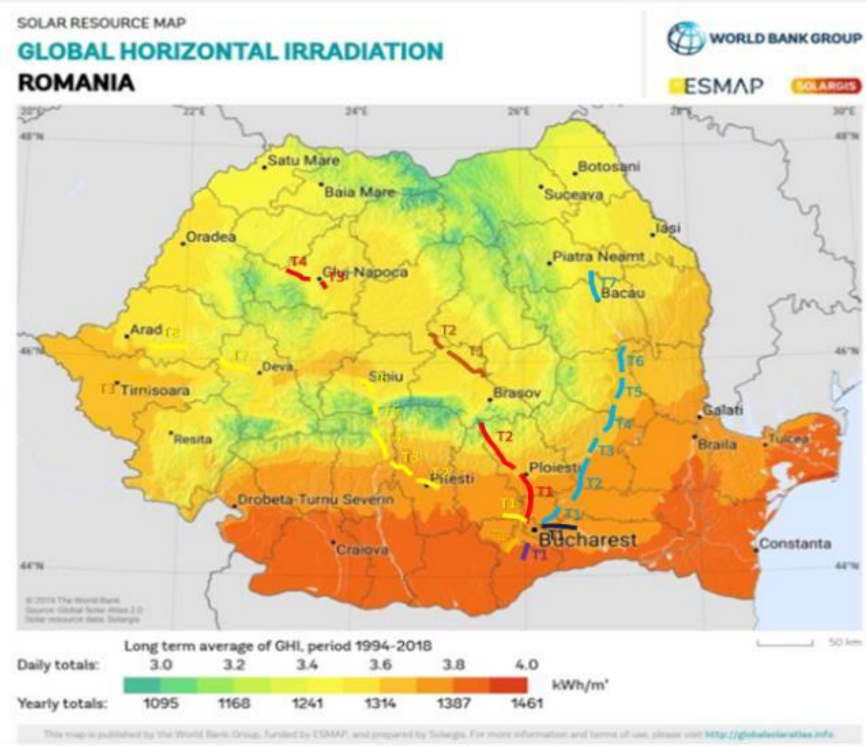

Figure 10. Average multi-year exposure to solar radiation – 1994-2018 [5]

Another "stressor" factor discussed in the literature is the daily traffic volume specific to each national road under consideration. For our country, we have taken into account the data for 2022, which is in the middle of the 2021-2023 interval. The combined situation of the factors discussed so far is shown in Table 1.

Table 1. Presentation of the factors involved

Simbolizare	Temperatura medie anualã [°C]	Cantitatea anuala de precipitaţii [mm] [l/m^2]	Traficul mediu zilnic de autovehicule [17]	Iradierea solarã orizontalã anualã [Kwh/m^2]
	T	***P***	***TR***	***S***
5	>14	>2000	>20000	1388 - 1461
4	10,1-14	1201-2000	15001- 20000	1315 1387
3	6,1-10	801-1200	10001- 15000	1242 1314
2	0,1-6	401-800	5001- 10000	1169 1241
1	<=0	<=400	<5000	970 – 1168

3.2 Vertical road signs

The measurement process resulted in a distribution of the average number of signs installed per kilometre of road investigated ranging from 4 to 12, as shown in Figure 11. The average for all national roads investigated in the six stages is 9 signs/km.

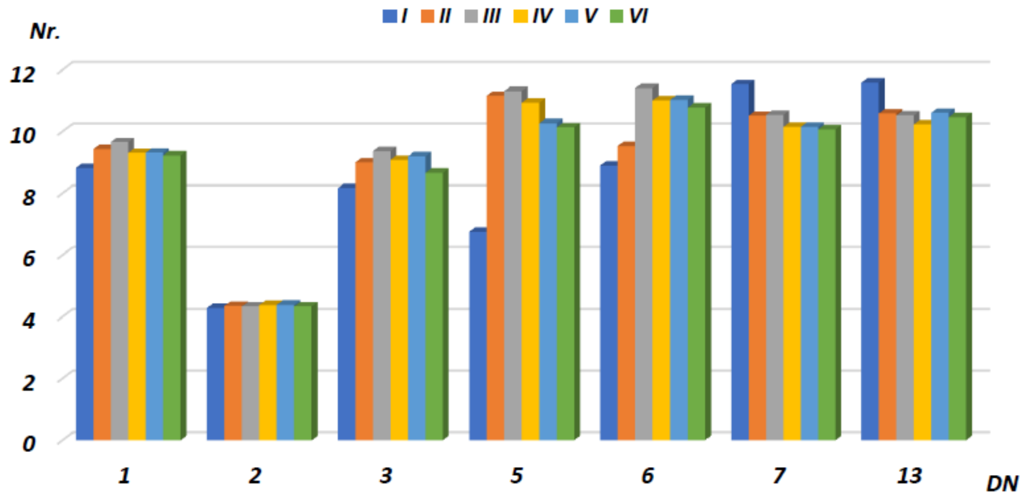

Figure 11. INDICATORS / Km in each stage

The percentage distribution of signs in each category for all measured national roads is shown in Figure 12. Their layout varies greatly from road to road, due to several factors, including traffic volume, speed limits, potential hazards and specific community needs. Technical studies and traffic assessments also play a crucial role in determining the appropriate signage for a given location.

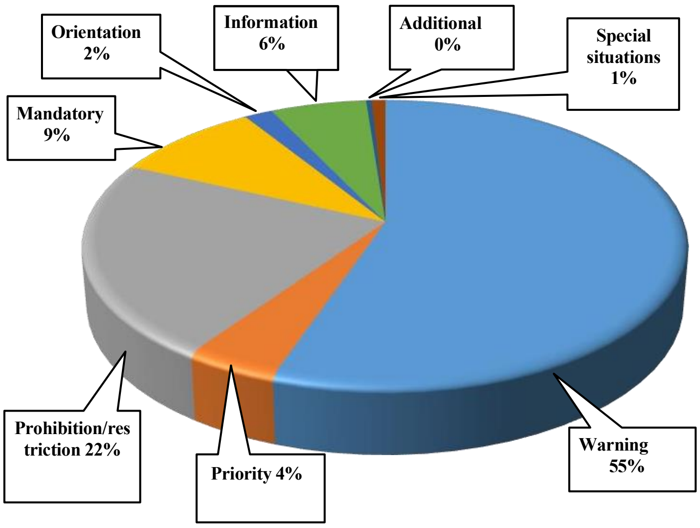

Figure 12. Average percentage distribution of signs by category across all measured national roads

In terms of the physical condition of the signs, they were sorted into 10 types of defects: bent, scratched, vandalised, discoloured, rusted, cracked, dirty, located in an area with poor visibility, peeling and unstable mounting. The average percentages for each category of defects on all roads surveyed are shown in Figure 13. These values were determined as the arithmetic mean of all measured sections, without considering the kilometre weight of each sector in the total kilometres investigated. The data presented in Figure 13 are based on the inspection of 74,393 road signs during the six stages.

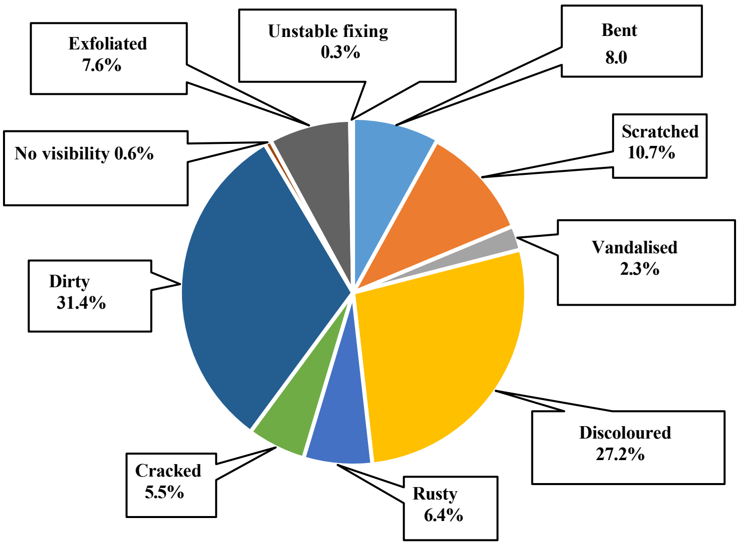

Figure 13. % classification by type of defect for all national roads surveyed

There are a multitude of factors that can cause defects or increase their rate of occurrence on road signs located along roads (weather, ageing, vandalism, accidents, vegetation growth around signs, traffic, harmful airborne agents, road altitude, sign height relative to road level, etc.).

Another important aspect regarding the quality of vertical signs is the RA coefficient value and how it changes over time. Comparing the RA values measured in stage 1 and stage 6, i.e. at an interval of 3 years, it can be seen that in most cases the coefficient fell within the same class, as shown in Figure 14.

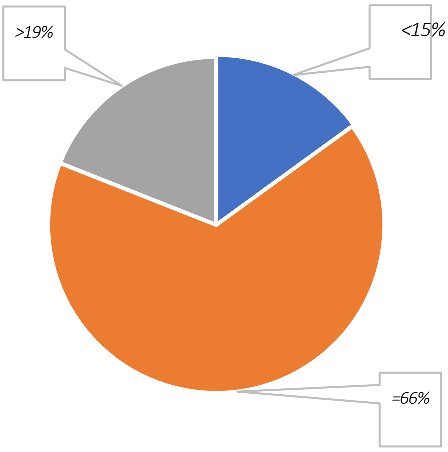

Figure 14. Variation in the "RA" coefficient, cumulative for all sections measured in stage 6 compared to stage 1

Another analysis that can be performed on the results of measurements taken on vertical road signs relates to the influence of climatic factors.

The maps presented above show the layout of the measured sections, both in terms of their orientation relative to the cardinal points and in terms of climate categories.

Weather conditions such as rain, drizzle, fog, dew and frost affect the visibility of traffic signs now due to changes in refraction and the scattering of light beams. There should be a direct link between lower RA values and solar radiation.

The interpretation of the results, by section, cannot lead to a firm conclusion, as not all situations converge towards a consistent result.

Therefore, a comprehensive option would be to judge the figures representing the arithmetic mean of the values for a group of irradiations, across all sections geographically located in the same category.

The result can be seen in Figure 15, which confirms a link between solar radiation intensity and the percentage decrease in RA retroreflection coefficient values.

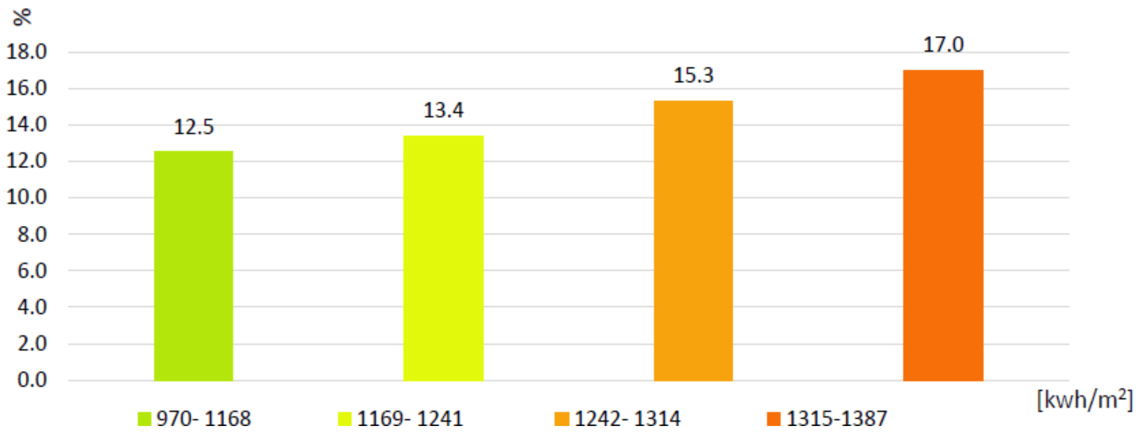

Figure 15. % decrease in RA values, depending on horizontal solar radiation

Another analysis can be performed by considering the relative position of vertical traffic signs in relation to the sun and what happens to the RA retroreflection coefficient.

The measured sections were divided for study into several directions, namely: S-N; E-W; SW-NE; NE-SW and SE-NW, considering the orientation of lane 1 of each road. The summary of these determinations is presented in Table 2.

Table 2. Average percentage of RA degradation

Exposure direction	Average % degradation
N - S	8
E – W	2
SW - NE	13
SE - NW	11
NE - SV	11

Without taking into account other factors specific to each section location and, implicitly, to the national roads checked, as well as the type of film used, it can be concluded that the traffic signs displayed in the E-W direction were most strongly negatively affected.

3.3 Horizontal road markings

The measurement of the RL retroreflection characteristic of horizontal road markings was carried out over a period of three years, twice a year. The following markings were measured: MDPC – road boundary marking, MDBAS – same direction lane boundary marking, AX – direction boundary marking.

As a summary of the data acquisition, at a global level, of the measured national roads, below is presented the average retroreflective luminance coefficient RL of the six measurement stages.

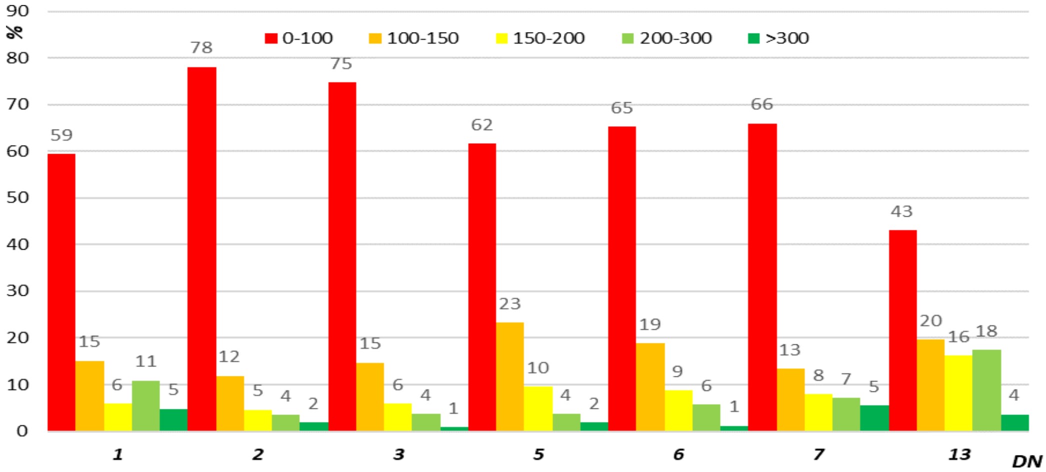

Figure 16. Percentage distribution of RL in each of the five groups on each national road, as an average across all six stages

The graph in Figure 16 shows that red is the predominant colour, which means that the average RL values for the 1,448 kilometres measured fall mainly in the lowest class (0–100 mcd/lx/m^2) with an average percentage of 64% on all national roads.

Below, we will attempt to use examples based on data collected in the field to illustrate the possible correlation between the rate of deterioration of road markings and certain environmental, traffic and time factors.

3.3.1 Distribution of RL and the percentage change, considering only the influence of the time elapsed between the first and last measurements

As can be seen in Figure 17, the degradation/day differs substantially from section to section and from road to road, which leads to the conclusion that there are many other elements that influence this rate, such as: the quality and type of material applied, the conditions at the time of application, daily traffic, weather conditions, the passage of snow ploughs, etc.

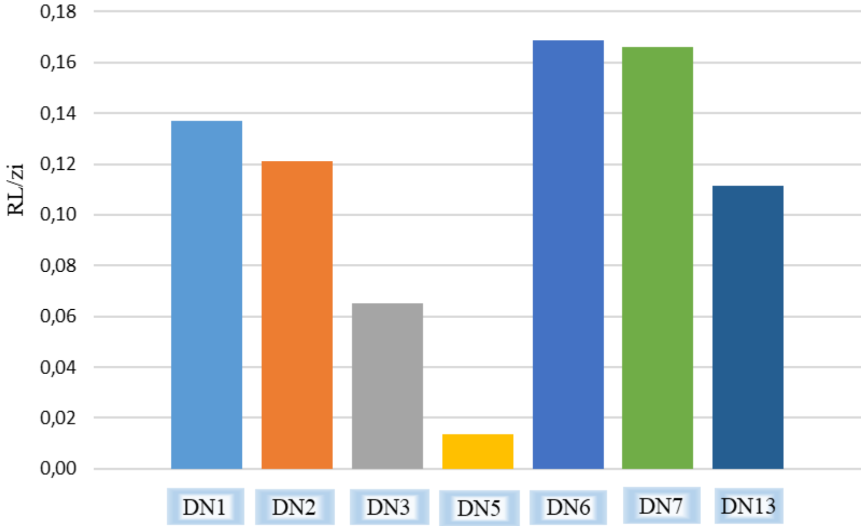

Figure 17. Average daily degradation of RL, per national road

3.3.2 Distribution of RL coefficient degradation, considering only the influence of precipitation

A discussion can be made regarding the influence that the annual amount of precipitation could have on the depreciation of the RL coefficient over time. The classification of the measured sections into precipitation groups can be seen in Table 3.

Table 3. Classification of measured sections into precipitation groups

DN	Section	No. of days	% variation	RL decrease value	Average decrease RL/day	Precipitation group [l/m^2 /year]	Average RL/day Group 1
1	1	760	10	13	0.02	<=400	0.07
2	1	910	14	12	0.01		
	2	777	25	24	0.03		
3	1	364	23	20	0.05		
7	4	423	25	61	0.14		
	7	510	49	68	0.13		
1	3	350	47	60	0.17	401 - 800	0.15
	4	235	73	45	0.19		
2	3	910	28	21	0.02		
	4	583	19	14	0.02		
	5	775	89	69	0.09		
	6	243	86	54	0.22		
	7	243	165	108	0.44		
5	1	349	2	2	0.01		
6	1	927	11	9	0.01		
	2	473	20	109	0.23		
	3	927	57	90	0.10		
7	1	933	0	0	0.00		
	2	755	83	270	0.36		
	3	933	70	190	0.20		
	5	423	118	124	0.29		

DN	Section	No. of days	% variation	RL decrease value	Average decrease RL/day	Precipitation group [l/m^2 /year]	Average RL/day Group 1
	6	778	190	153	0.20		
	7	933	0	0	0		
13	1	332	66	53	0.16		
	2	332	25	21	0.06		
1	2	235	54	57	0.24	801 - 1200	0

As can be seen, the differences (minimum – maximum) in the decrease in RL per day within each precipitation group are not uniform, 0.13 for precipitation group 1 and 0.36 for precipitation group 2.

For this reason, we chose to represent the average of each precipitation group, as shown in Figure 18.

The result could be interpreted simplistically by the fact that precipitation does indeed have some influence on degradation, but at the same time we believe that the influence is due more to the possible removal of snow and ice in areas with more precipitation.

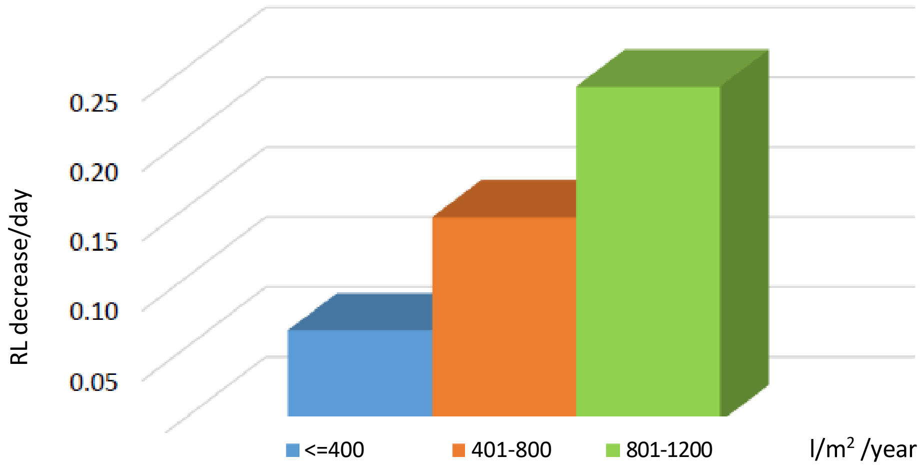

Figure 18. Average daily degradation of RL, depending on the precipitation group

3.3.2 Distribution of RL coefficient degradation, considering only the annual daily average of motor vehicle traffic

As we have seen in previous presentations, the RL coefficient decreases over time, but other negative influences also intervene and accumulate. It was necessary to see if traffic has an influence on longitudinal markings. To do this, we only considered MDBAS (same direction lane marking) and AX (traffic direction marking) markings, as these are the most susceptible to damage from being run over by wheels when overtaking or changing lanes.

As can be seen, as in the graphs representing the influence of time and precipitation, the distribution is heterogeneous, which supports the hypothesis that the durability of markings is influenced by several cumulative factors and not just one.

Since within each traffic group the minimum-maximum differences in RL values are 0.22 for the 5001-10000 vehicles/day group, 0.25 for the 10001-15000 vehicles/day group, 0.25, and for the group 15001-20000 vehicles/day, 0.56, for interpretation purposes we calculated the average decrease values for each group separately, the result being shown in the graph in Figure 19.

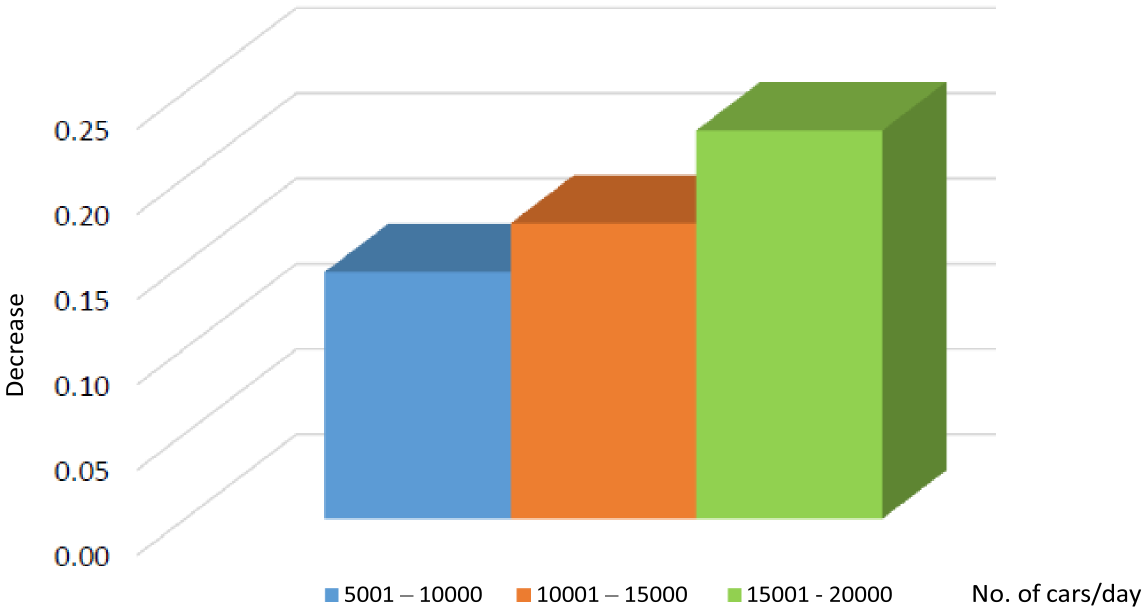

Figure 19. Change in RL/day for MDBAS and AX depending on traffic

3.3.3 Distribution of RL coefficient degradation, considering only annual horizontal solar irradiation

The methodology applied is similar to that used for the other influencing factors. We considered that the deterioration of road markings may be directly proportional to the degree of exposure to the sun and the intensity of the radiation produced by it. The classification of the measured sections into the corresponding solar radiation groups can be found in Table 4.

Table 4. Symbolisation of solar radiation groups

Group	Annual horizontal solar radiation [Kwh/m2]
5	**1388 - 1461**
4	**1315 1387**
3	**1242 1314**
2	**1169 1241**
1	**970 – 1168**

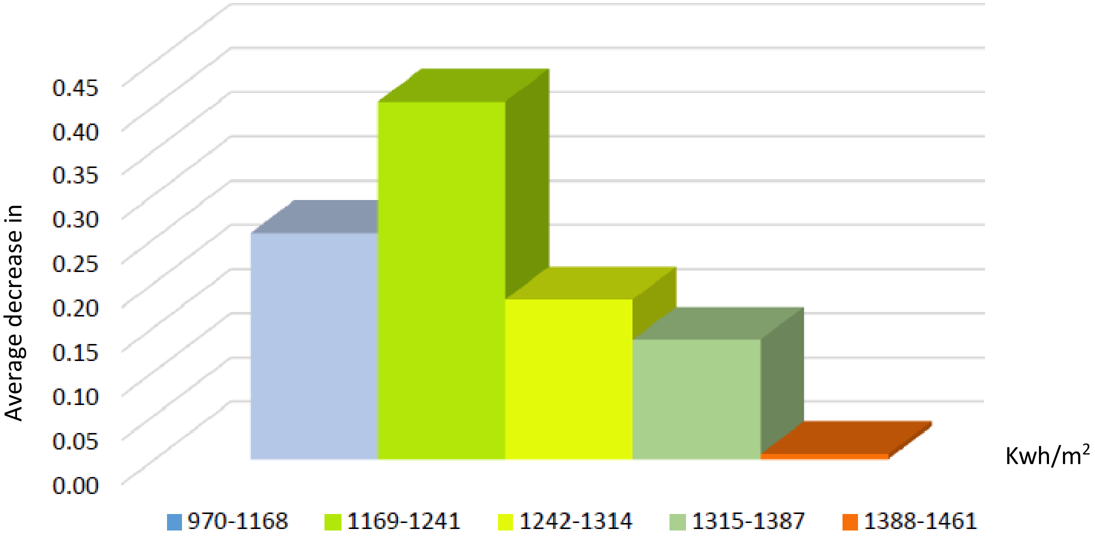

Figure 20. Average RL variation per day, depending on the solar radiation group

The conclusion regarding the influence of road markings exposure to different solar intensities on the measured sections does not confirm the initial hypothesis, as can be seen in Figure 20.

Apparently, the influence would be inversely proportional to the intensity of radiation, which borders on elementary logic. This inverse trend could be explained by the local existence of other unknown factors with a major influence.

4. CONCLUSIONS

Retroreflective road signs and pavement markings are critical elements of road infrastructure, particularly for ensuring driver guidance and safety under nighttime and reduced-visibility conditions. Their effectiveness depends on the ability of retroreflective materials to return vehicle headlamp light toward the road user, which is commonly quantified using the coefficient of retroreflection RA for traffic signs and the coefficient of retroreflected luminance RL for longitudinal pavement markings.

Regarding *the RA retroreflection coefficient values* of vertical road signs, the following general conclusions can be drawn:

- RA values remained equal in 66% of the total number of signs measured over a three-year period.
- The maximum percentage of defective signs by category is: bent - 21%; scratched - 39%; vandalised - 7%; discoloured - 61%; rusted - 43%; cracked - 40%; dirty- 72%; not visible - 5%; peeling - 26%; loosely fixed - 2%;
- the proportion by colour of the RA coefficient with lower values in stage 6 compared to stage 1 is: white - 47%; blue - 8%; red - 32%; yellow - 13%;
- the degradation of RA values depends on the degree of horizontal solar irradiation.
- the degradation of RA values is influenced by the orientation of the indicator relative to the cardinal points.

Regarding the values of the retroreflected luminance coefficient RL of road markings, the following general conclusions can be drawn:

- the average RL coefficient, with values ranging from 0 to 100 mcd/lx/m^2 on the measured sections, covers between 25% and 97% of the length of each section;
- the average on each of the seven national roads, as an average of the values on each section, is between 43% and 78%;
- the average on all 7 national roads is 64%. The link between RL values and certain external factors:
- number of days of exposure – the interpreted data did not clearly reveal what type of link exists between time and depreciation and according to which mathematical law this occurred;
- cumulative precipitation – the processed data revealed that the deterioration was more pronounced in direct proportion to the increase in precipitation volume;
- cumulative motor vehicle traffic – the average motor vehicle traffic volume influences the degradation of road markings, particularly the RL coefficient;
- horizontal solar radiation – the values determined do not confirm a direct link between the RL coefficient and the degree of radiation. There may be a correlation between the measured RL value and the moment of solar exposure corresponding to the situation at the time of measurement. The veracity of this hypothesis is worth investigating in the future.

In order to be able to interpret the data collected in the field more accurately in the future, information on the asphalt surface, the type of material used for marking, the weather conditions at the time of application, the date of marking, etc. should also be added. In addition to long-term degradation, short-term environmental and operational factors—such as weather conditions, surface contamination, and traffic intensity—can significantly influence measured retroreflectivity values. These effects introduce variability into field measurements and highlight the importance of consistent measurement protocols, appropriate sampling strategies, and thorough documentation of test conditions. Failure to account for these factors may lead to misinterpretation of retroreflective performance and suboptimal maintenance decisions.

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