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Analysis of optical parameters of materials used for road markings

Abstract: The study aimed to determine the optical parameters of road pavement markings using both stationary and dynamic measurement methods. The research described in the article was conducted on ten road sections with different surface types and marking technologies. The analyses enabled the determination of the retroreflection coefficient R_L, luminance coefficients Q_D/β, and verification of marking contrast. The practical feasibility of using the dynamic method to determine contrast DC and evaluate road markings was demonstrated. Results indicated significantly higher R_L and Q_D values for thick-layer markings compared to those of thin-layer markings. For example, the minimum required R_L value for expressways is 150 mcd/lx/m^2. In contrast, the surveyed sections achieved thick-layer markings of up to 573 mcd/lx/m^2, while thin-layer markings ranged from 25 to 185 mcd/lx/m^2. The conclusions highlight the need for regular monitoring of marking conditions (especially R_L and Q_D), the use of materials that ensure durable retroreflection, and the utilisation of dynamic measurements for assessing longer road sections.

Keywords: dynamic/stationary methods, pavement marking, retroreflection, traffic safety, visibility.

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1. INTRODUCTION

Road traffic safety depends on many factors and results from the interaction of road-user-environment relationships [1]. Therefore, it is essential to have proper and legible road markings to establish the rules of movement for road traffic participants unambiguously [2]. Maintenance of pavement markings is crucial for appropriate road management. The service life and durability of road markings depend directly on mechanical wear caused by vehicle traffic. It is a well-established fact that the values of the retroreflection coefficient R_L and the luminance coefficient under diffuse illumination Q_D decrease as traffic intensity increases. Consequently, monitoring these parameters is essential for ensuring safety (particularly during investment works related to non-standard vehicle trajectory adoption). Road markings serve a fundamental function in directing vehicle traffic, indicating lane boundaries and conveying instructions and warnings to road users. These functions can be fulfilled adequately if the markings are visible to users. Visibility is achieved through contrast between the marking and the road surface [3-4]. The selection of materials and structural features of road markings is therefore essential. They should be characterised by high resistance to changing traffic conditions while ensuring visibility [5] and resistance to vehicle skidding [6]. One should always choose materials with the best durability, i.e., those that provide the most extended possible service life. Significant differences in the rate of material erosion emphasise the necessity of their appropriate selection for a specific area [5].

The applicable requirements in Poland are specified by the standard PN-EN 1436 [7] and the Regulation of the Minister of Infrastructure regarding detailed technical conditions for road signs and signals [8]. The PN-EN 1436 standard presents requirements for pavement road markings and methods for their testing [7]. From the perspective of road traffic safety, the key normative parameters are nighttime visibility, daytime visibility, and skid resistance, which are assessed through the values of, respectively:

- retroreflection coefficient R_L (nighttime visibility),
- luminance coefficient in diffuse light Q_D, luminance coefficient β, and chromaticity coordinates x, y (daytime visibility),
- skid resistance index *SRT* (skid resistance).

To determine the indicated parameters, in accordance with the standard, two measurement methods are distinguished: stationary and dynamic. The first method uses a point reflectometer, requires traffic stoppage, and employs appropriate work safeguards to ensure the safety of personnel conducting the measurement. Although it is simple to perform, it is characterised by labour and time intensity. The stationary method is therefore ineffective for long road sections and is challenging to apply on roads with high traffic volumes. An alternative is the dynamic method, which uses a vehicle equipped with a reflectometer mounted on the car for measurement. The fundamental difference between the indicated measurement techniques lies in the measurement registration accuracy, which is ±1 mm for the stationary method and ±5 mm for the dynamic method, respectively. Additionally, the dynamic method is characterised by limitations related to its application in atmospheric conditions. Due to the possibility of sensor contamination, measurements should be conducted on a dry road surface. The indicated limitations are compensated for by measurement efficiency, which allows measurements to be registered at a uniform speed of up to 90 km/h, enabling testing on long road sections without posing hazards to personnel conducting the measurement and without impacting traffic flow. Additionally, the daytime contrast parameter is automatically calculated, allowing for a quick assessment of marking visibility.

According to the standard [7], the parameter describing the visibility of pavement markings is the light reflection coefficient. The effectiveness of the light reflection coefficient depends primarily on factors related to the type and condition of the road surface or marking/marking and the angle of the driver's approach. Research shows that better reflectivity correlates with a lower accident rate, which underscores the necessity of rigorous testing and standardisation of road marking materials [9-11]. In this context, methods for assessing performance in real traffic conditions enable better adaptation of road marking design to needs, which translates into increased safety [12]. The selection of pavement marking components plays a vital role in terms of durability and ensuring visibility. Extended service life translates to 50% savings in material consumption, 50-97% lower emissions of volatile organic compounds, and a reduction in long-term financial costs of 5-26% [13]. For example, water-based materials have the advantage in terms of environmental impact, providing performance and durability in various weather conditions [14-15]. In turn, components containing glass beads that enhance retroreflection increase visibility at night or in adverse weather conditions [16-17]. Work is also being conducted on the application of photoluminescent marking, which increases nighttime visibility and improves safety [18]. Additionally, an alternative to traditional pavement markings using light-emitting elements for their execution is noteworthy. While the indicated approach has significantly higher execution costs, it may be applicable in locations characterised by serious accident risk or in so-called difficult traffic conditions [19].

Research indicates that the distinctness of road markings affects the speed at which drivers develop and their perception of space. Wider longitudinal markings have a positive impact on driver compliance with regulations, leading to a reduced risk of accidents on these road sections [20-21]. In contrast, deteriorating road marking conditions lead to their illegibility, which can contribute to a higher number of accidents. This relationship is confirmed by research results that show how road marking quality affects driver behaviour. This confirms the need for regular maintenance and timely updates to the quality of markings [22-23]. An important issue is also determining the typical road lighting on the surveyed section, given the possible contrast achievable between the surface and the planned marking technology. This translates into the effectiveness of the impact on safety in the context of the contrast between the road surface and the planned marking technology [24].

The primary aim of this study was to evaluate the correlation between the standard luminance coefficient Q_D and the dynamic contrast index DC to determine if dynamic methods can effectively replace stationary measurements for daytime visibility assessment. By analysing road sections with varying surface types (asphalt vs. concrete) and marking technologies (thin-layer vs. thick-layer) under defined traffic loads, this research investigates whether the non-standardised DC parameter can serve as a reliable predictor for the standardised Q_D coefficient. Furthermore, the study quantifies the impact of marking technology and substrate type on the durability of optical parameters (R_L, Q_D), providing a scientific basis for optimising material selection and understanding the limitations of dynamic contrast metrics in diverse operating conditions.

2. METHODS

The road sections used in the study were selected based on the criterion of the most frequently occurring configurations of pavement markings and road surfaces encountered on Polish roads. The analysis took into account both the marking execution technologies and diverse wear layer substrates. The research program aimed to compare the effectiveness of optical parameter and retroreflection measurements performed using stationary and dynamic methods. The main criteria for selecting road sections included:

- marking execution technology type: thick-layer (structural, profiled, reflective barrier, reflective bead) and thin-layer,
- material type: paints, thermoplastic or chemically hardened compounds,
- wear layer surface type: SMA (mineral-asphalt mixture with limestone powder additive), AC (asphalt concrete), cement concrete,
- marking service life period: new markings (up to 2 years), in-service (over 3 years),
- location of the research section (national roads, provincial and urban roads with varying traffic loads),
- type of markings subject to analysis (e.g., edge lines, segregation lines; types: P-7a, P-7b, as data availability permits),
- measurement section length of 300 meters,
- measurement frequency every 2-3 meters,
- comparative measurements using both methods for the same measurement sections.

Each of the tested roads was divided into measurement sections in accordance with normative requirements, resulting in a range of 98 to 150 measurements for each location.

In accordance with the adopted criteria, road sections for testing were identified as shown in Table 1. The most frequently used mineral-asphalt mixtures for the wear layer execution are SMA and asphalt concrete (AC).

It is important to note that the study encompasses both edge lines (P-7b) and segregation/centerlines (P-1), as detailed in Table 1. Direct comparison between these types of markings requires caution due to their radically different operating conditions. Centerlines are subjected to significantly higher mechanical wear caused by frequent wheelovers during overtaking and lane-changing manoeuvres.

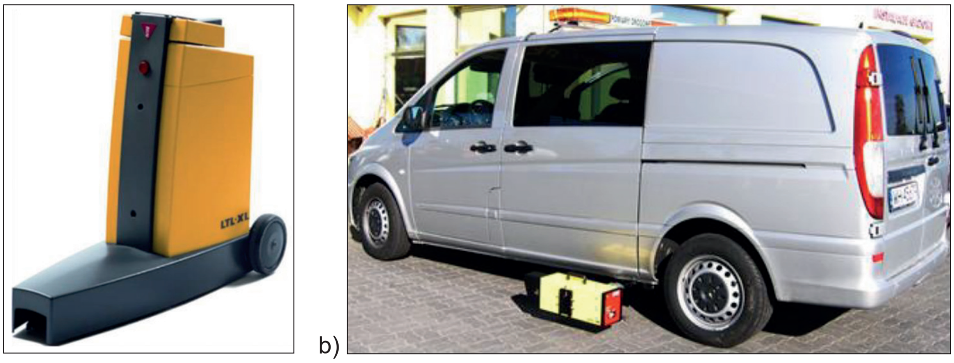
Conversely, edge lines, while less mechanically stressed, are more susceptible to the accumulation of dirt and debris, which can affect optical readings. Therefore, in the subsequent analysis, these differences in location-specific degradation mechanisms are taken into account when interpreting the durability and visibility results.

In Poland, commonly used devices for measuring the luminance coefficient in diffuse light Q_D, and the retroreflection coefficient R_L, are handheld (portable) reflectometers. They simulate lighting conditions and allow observation of markings at distances up to 30 m under a slight angle of incidence (1.24°) and a slightly larger observation angle (2.29°), which complies with the requirements of the PN-EN 1436 + A1:2008 standard. The situation is simulated, where the distance of a passenger car driver from the measured marking is 30 m, the position of the car's reflectors is at a height of 0.65 m, and the line of sight is directed at a level 1.2 m above the road surface. Measurements of the luminance coefficient β, in diffuse light Q_D, and the retroreflection coefficient R_L were performed in accordance with the methods described in PN-EN 1436 + A1:2008.

The measurements utilised a stationary reflectometer, LTL-XL, and a mobile reflectometer, LTL-M (Fig. 1). The stationary LTL-XL device measures the amount of reflected light using a precise point-detector system, presenting results in mcd/m^2 · lx. In contrast, the dynamic measurements were conducted using a vehicle-mounted LTL-M mobile reflectometer system, which operates based on machine vision technology. Unlike stationary point measurements, the dynamic system utilises a high-speed camera and an advanced image processing unit to continuously record the geometry and luminance of the road markings at typical traffic speeds (up to 90 km/h). The system geometry simulates the standard observation distance of 30 m (CEN geometry), ensuring comparability with stationary handheld devices. The measurement frequency allows for the acquisition of over 25 data points per second, which are then integrated to provide average values for defined road segments. The specific advantage of this method lies in the simultaneous acquisition of the retroreflection coefficient R_L and the calculation of daytime contrast *DC* based on the luminance ratio between the identified marking region of interest (ROI) and the adjacent road surface background in the video frames. Measurements of the retroreflection coefficient R_L should be performed on dry markings. It is possible to measure the retroreflectivity of flat, textured, and profiled markings, single and double lines, continuous and dashed, with widths ranging from 10 cm to 50 cm.

Table 1. Characteristics of the Research Test Site [25-26]

No.	Road	Marking Type	Tested Objects	Mineral-Asphalt Mixture Type	Annual Average Daily Traffic [number of vehicles]
1	DW632 → Wyszków	thin-layer full	right edge line (P-7b)	AC	3,840
2	Żyrardowska St. in Warsaw	thin-layer full	segregation line (P-1)	AC	–
3	Akacjowa St. in Kąty Węgierskie	thin-layer full	segregation line (P-1)	AC	–
4	DW630 → Nowy Dwór Maz.	thin-layer full	left continuous edge line (P-7b)	SMA	20,942
5	DW630 → Warszawa	thin-layer full	right dashed edge line (P-7a)	SMA	32,240
6	S8 Wyszków	thick-layer structural MDL	right edge line (P-7b)	SMA	**7,237**
7	DK61 → Pułtusk	thick-layer profiled	right edge line (P-7b)	SMA	**5,373**
8	DK50 Młodzieszyn → Wyszogród	thick-layer full	right edge line (P-7b)	cement concrete	33,867
9	DK7 Pułkowa St.	thick-layer structural full-reflective tape	right edge line (P-7b)	SMA	43,779
10	Gardziejewskiego St. in Warsaw	thick-layer structural – "baranek"	left edge line (P-7b)	SMA	21,113



a) b)

Fig. 1. Research equipment used – reflectometer: a) LTL-XL, b) LTL-M (mounted on a vehicle); source: own elaboration

Based on the obtained measurement data, daytime contrast is calculated using the specific measurement method. Daytime contrast is understood as the difference in appearance between two parts of the field of view (in this case, the marking and the road surface). The higher the value of the *DC* parameter, the more visible the marking is to the driver during the day. In the case of recordings obtained using the LTL-M mobile reflectometer, the contrast is calculated using formula (1):

$$DC = \frac{E_{\text{ozn}} - E_{\text{naw}}}{E_{\text{naw}}}, \tag{1}$$

where:

E_{ozn} – marking luminance [cd/m^2],

E_{naw} – road surface luminance [cd/m^2].

For measurements using the stationary method with the LTL-XL handheld reflectometer, the contrast DC_{QD} is calculated using formula (2):

$$DC_{\text{QD}} = \frac{Q_{\text{Dozn}} - Q_{\text{Dnaw}}}{Q_{\text{Dnaw}}}, \tag{2}$$

where:

Q_{Dozn} – luminance coefficient Q_{D} of the marking [mcd/m^2 · lx],

Q_{Dnaw} – luminance coefficient Q_{D} of the road surface [mcd/m^2 · lx].

Additionally, for the tested road sections, the luminance coefficient was also determined in accordance with normative requirements using a MiniScan XE Plus colorimeter by HunterLab with a measurement geometry of 45/0. The β parameter describes the ability of pavement markings to reflect daylight in the direction of the driver. The contrast DC_β determined using the MiniScan EZ spectrophotometer is calculated using formula (3):

$$DC_\beta = \frac{\beta_{\text{ozn}} - \beta_{\text{naw}}}{\beta_{\text{naw}}}, \tag{3}$$

where:

β_{ozn} – luminance coefficient β of the marking,

β_{naw} – luminance coefficient β of the road surface.

3. RESULTS

Based on the measurements performed for the selected road sections using the LTL-XL point meter and the mobile LTL-M, the results presented in Table 2 were obtained. The compilation also includes calculations for daytime contrast DC_{QD} and DC_β.

Analysis of the measurement results for pavement marking parameters presented in Table 2 allows for an assessment of the quality and effectiveness of the applied pavement marking technologies on various road sections. According to the regulations in force in Poland, pavement markings should meet technical requirements related to R_{L} for motorways 200 (class R4), expressways 150 (class R3), and other roads 100 (class R1, in the case of unlit roads). For the luminance coefficient β, the values are 0.32 for motorways and expressways, and 0.30 for other roads. It should be noted that for road sections numbered 2, 4, 5, 6, and 8, the basic requirements for the retroreflection coefficient R_{L} are not met, which may indicate a significant degree of marking wear or inappropriate material selection for its execution. In the case of the luminance coefficient in diffuse light Q_{D}, high values were recorded for sections 5 (222 mcd/m^2 · lx) and 4 (196 mcd/m^2 · lx). These values suggest high legibility of the marking in daylight. The lowest Q_{D} values (<60) occurred on sections with thick-layer markings or heavily worn markings (e.g., the S8 route, Żyrardowska St.), which may lead to reduced daytime visibility. In the case of the luminance coefficient β, the minimum value was not obtained for sections 2, 8, and 9. The highest β value was achieved on the S8 route (0.647), which may be attributed to the use of thermoplastic or chemically hardened compounds with high wear resistance and high retroreflectivity. Daytime contrast DC, regardless of the adopted measurement method (DC, DC_{QD}, DC_{β}), achieved values above 1 for all sections, which means that the marking was distinguishable from the road surface. The highest contrast values were recorded for DK61 ($DC = 3.82$) and the upper limit. Gardziejewskiego St. ($DC_{\beta} = 4.97$), indicating excellent visibility of the pavement marking relative to the background.

The linear regression analysis performed on measurement data from the selected road sections allows for an assessment of the relationship between the luminance coefficient and daytime contrast indicators. The obtained values of the coefficient of determination R^2 indicate that the strength of the examined relationships varies, ranging from very weak to moderate.

- The relationship between the luminance coefficient Q_D and daytime contrast DC is characterised by a very low $R^2 = 0.1478$ value, indicating weak correlation and limited applicability of this regression model in the context of descriptive assessment of the phenomenon.
- A high fitting level was achieved for the relationship between daytime contrast DC and DC_{β} ($R^2 = 0.6047$), indicating a moderately strong relationship between these parameters.
- The correlation between daytime contrast DC and DC_{QD} reached a low fitting level ($R^2 = 0.2022$), suggesting weak linear dependence.
- The relationship between daytime contrast DC and DC_{β} is characterised by a moderately good coefficient of determination value ($R^2 = 0.4903$), confirming a relatively straightforward relationship between the analysed indicators.
- The lowest value was recorded for the relationship between the luminance coefficient Q_D and the luminance coefficient β ($R^2 = 0.033$), indicating an absence of significant linear correlation.

Table 2. Comprehensive compilation of research results for pavement marking parameters

Location	LTL-XL						LTL-M		Calculations	
	Marking			Road surface			Marking			
	R_L	Q_D	β	R_L	Q_D	β	R_L	DC	DC_{QD}	DC_{β}
	$mcd \cdot m^{-2} \cdot lx^{-1}$	$mcd \cdot m^{-2} \cdot lx^{-1}$	cd/m^2	$mcd \cdot m^{-2} \cdot lx^{-1}$	$mcd \cdot m^{-2} \cdot lx^{-1}$	cd/m^2	$mcd \cdot m^{-2} \cdot lx^{-1}$	[–]	[–]	[–]
DW632 → Wyszków	185	145	0.323	5	53	0.076	182	2.15	1.74	3.25
Żyrardowska St. in Warsaw	64	120	0.256	10	59	0.092	86	2.08	1.03	1.78
Akacjowa St. in Kąty Węgierskie	422	175	0.458	13	71	0.101	438	2.91	1.46	3.53
DW630 → Nowy Dwór Maz.	42	196	0.363	4	52	0.065	51	3.23	2.77	4.58
DW630 → Warszawa	25	222	0.323	4	51	0.066	222	2.83	3.35	3.89
S8 Wyszków	96	107	0.647	9	48	–	96	2.58	1.23	–
DK61 → Pułtusk	180	157	0.361	9	53	0.071	176	3.82	1.96	4.08
DK50 Młodzieszyn → Wyszogród	120	135	0.258	9	88	0.149	116	2.2	0.53	0.73
DK7 Pułkowa St.	573	136	0.269	6	54	0.069	533	2.92	1.52	2.90
Gardziejewskiego St. in Warsaw	205	146	0.412	4	56	0.069	2,28	3.45	1.61	4.97

In light of the obtained results, it can be stated that among the analysed variable combinations, the pair DC-DC_{β} exhibits the most significant predictive value for linear regression models.

4. DISCUSSION

The type and texture of the road surface were identified as significant determinants of the optical performance indicators. As shown in the results for the concrete section (DK50), the light grey colour of the cement concrete surface naturally possesses a high luminance coefficient, which significantly reduces the available contrast *DC* for white markings compared to dark asphalt surfaces (SMA/AC). Even with high-quality marking material, the *DC* value on concrete is inherently lower due to the brighter background.

Furthermore, surface roughness plays a dual role. While macro-texture is essential for skid resistance, excessive roughness or texture depth on worn asphalt can lead to the “shadowing” of glass beads or their premature detachment, directly contributing to the low R_L values observed on older sections. This effect is less pronounced on smoother concrete surfaces; however, the lack of contrast remains the primary limitation in this case. Thus, the low correlations observed are partly attributable to these varying substrate interactions that affect *DC* and R_L differently.

Given the weak correlation found between *DC* and the standardised Q_D, establishing a universal *DC* threshold is scientifically challenging. Therefore, the value of 1.8 identified in this study is not proposed as a rigid, arbitrary standard, but rather as a conditional baseline for concrete surfaces, supported by perceptual studies. We explicitly advise against using this threshold for asphalt surfaces without applying a correction factor, as the higher background contrast on asphalt typically yields significantly higher *DC* values for the same marking quality.

An attempt was made to identify a potential reference threshold for the *DC* contrast coefficient based on the collected data. On the examined road sections, the obtained average values of the *DC* contrast coefficient ranged from 2.08 to 3.82. The analysis showed that the lowest *DC* contrast coefficient result was obtained for markings on cement concrete surface – approximately 1.8, with a Q_D value of roughly 100 mcd/m^2 · lx. Visual assessment indicates that under conditions of weak sunlight, this marking will have sufficient daytime visibility. This observation aligns with recent psychophysical studies on road marking contrast, which suggest that contrast values in this range are close to the threshold of adequate visibility for drivers [3].

A contrast coefficient value *DC* of 1.8 between the marking and cement concrete surface can, under certain conditions, be considered as providing visibility [3-4], [27]. However, such a level is insufficient in the case of markings on asphalt surfaces. At the present stage, it cannot be definitively determined what level of contrast should be standardised for various pavement markings, depending on the type of road surface, without further perceptual research.

The weak correlation ($R^2 = 0.1478$) observed between the luminance coefficient under diffuse illumination (QD) and the dynamic contrast index *DC* is not accidental. Instead, it results from fundamental differences in the physical definitions of these parameters. Q_D is an intrinsic optical property of the marking material itself, measured under standardised diffuse lighting conditions (EN 1436). In contrast, *DC* is a relative parameter that depends heavily on the luminance of the surrounding road surface. Consequently, a marking with a high Q_D value may exhibit a low *DC* index if applied to a bright surface (e.g., cement concrete), whereas a marking with a moderate Q_D can show a high *DC* on a dark, fresh asphalt surface. Therefore, the variability of the road surface background introduces significant “noise” into the relationship, making it impossible to predict *DC* solely based on Q_D without accounting for the pavement type.

The apparent discrepancy between the widespread failure to meet nighttime visibility requirements R_L and the consistently sufficient daytime contrast *DC* observed across the tested sections is physically justifiable. R_L relies primarily on the presence and quality of retroreflective glass beads, which are the first elements to be lost due to mechanical wear from traffic [28]. In contrast, *DC* (and daytime visibility in general) depends mainly on the diffuse reflectance of the marking material’s pigment (whiteness) relative to the road surface [29]. Consequently, a marking can lose its retroreflective beads (resulting in critically low R_L) while retaining enough pigment to maintain adequate daytime contrast against a dark asphalt background. This finding highlights that mechanical wear degrades nighttime performance significantly faster than daytime visibility, necessitating separate monitoring strategies for these two parameters.

5. CONCLUSIONS

The study aimed to verify whether there is a relationship between the daytime contrast coefficient *DC* measured with the mobile reflectometer LTL-M and the luminance coefficient in diffuse light Q_D determined with the stationary reflectometer LTL-XL. Why is the analysis of this relationship necessary? In the current state of European standardisation, the primary required parameters for pavement markings are visibility under daytime conditions (determined based on the luminance coefficient in diffuse light Q_D) and visibility under nighttime conditions (determined based on the retroreflection coefficient R_L); therefore, measurements of pavement markings with a mobile reflectometer LTL-M allow assessment of only the nighttime visibility parameter. The measurement data generated by the LTL-M mobile reflectometer software are the retroreflection coefficient R_L and the daytime contrast coefficient *DC*, a non-standardised parameter. To fully utilise the results from the mobile reflectometer LTL-M, knowledge of the relationship between the daytime contrast coefficient *DC* and the luminance coefficient in diffuse light Q_D would allow analysis to assess the visibility of pavement markings during the day without the need for additional measurements with a handheld reflectometer (Q_D coefficient). Technical specifications require classification of this marking to a specific class for R_L and Q_D parameters.

The linear regression analysis performed using the measurement data revealed varied strengths of relationships between the examined indicators. The highest fitting level was found for the relationship between daytime contrast *DC* and DC_β ($R^2 = 0.6047$), indicating a moderately strong linear relationship. Other relationships, including those between the luminance coefficient Q_D and daytime contrast *DC*, and the luminance coefficient β, were characterised by low values of the coefficient of determination (R^2 below 0.2), indicating a weak correlation. These results suggest a limited possibility of predicting one indicator based on another, except for the selected pair DC-DC_β, which shows potential for further analysis.

Based on the measurements of pavement marking visibility on selected road sections, it was found that:

- Visibility of pavement markings differs significantly depending on the execution technology and age of the marking. The best results were achieved on sections with thick-layer structural markings, particularly where reflective tapes or thermoplastic compounds were used.

1. Many thin-layer marking sections lack an appropriate level of nighttime retroreflectivity, which means failure to meet the normative values of the R_L coefficient, especially on roads with high traffic volumes or in conditions of limited lighting. This may have a direct impact on road user safety.
2. The daytime contrast parameter *DC* was at a level on all sections that allowed proper identification of the marking, indicating good marking visibility during the day, regardless of material and technology.
3. The best results were obtained on sections where the marking was relatively new or executed using materials with high retroreflection, such as those containing glass microspheres, or on surfaces with low luminance (darker), which enhances contrast.
4. To improve road traffic safety, systematic monitoring of marking condition is essential, as well as the implementation of new material solutions (e.g., photoluminescence, active marking), especially on sections with serious accident risk or in difficult atmospheric conditions.
5. Road managers should strive to use materials with more extended service life periods, particularly where intensive winter conditions or heavy traffic accelerate marking wear.

The demonstrated weak correlation between *DC* and Q_D constitutes a significant adverse finding, indicating that current dynamic methods cannot yet fully replace stationary measurements for assessing daytime visibility. This necessitates further research focused on two key directions: 1) developing advanced dynamic algorithms that compensate for variable ambient lighting and road surface luminance (e.g., using multi-spectral imaging), and 2) establishing specific *DC* correction factors for different pavement classes (cement concrete vs. asphalt). Future studies should also verify if measuring contrast under controlled artificial lighting (nighttime dynamic contrast) could provide a more stable predictor for daytime Q_D than the current sunlight-dependent method.

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Analiza parametrów optycznych materiałów stosowanych do poziomego oznakowania dróg

Streszczenie: Celem pracy było określenie parametrów optycznych oznakowania poziomego na drogach, z wykorzystaniem metody stacjonarnej i dynamicznej. Badania opisane w artykule przeprowadzono na dziesięciu odcinkach dróg o różnych nawierzchniach oraz technologiach wykonania oznakowania. Analizy pozwoliły na określenie parametrów współczynnika odblasku R_L, współczynników luminancji Q_D/β oraz weryfikację kontrastu oznakowania. Wykazano praktyczną możliwość stosowania metody dynamicznej do wyznaczenia kontrastu *DC* i oceny oznakowania. Wyniki wskazały na znacznie wyższe wartości R_L oraz Q_D dla oznakowania grubowarstwowego względem cienkowarstwowego. Przykładowo, dla R_L minimalna wymagana wartość dla dróg ekspresowych to 150 mcd/lx/m^2, natomiast na badanych odcinkach oznakowania grubowarstwowe osiągały nawet 573 mcd/lx/m^2, a cienkowarstwowe 25-185 mcd/lx/m^2. Wnioski wskazują na potrzebę regularnej kontroli stanu oznakowania (szczególnie pod kątem R_L i Q_D), stosowania materiałów zapewniających trwałość retrorefleksji oraz wykorzystania pomiarów dynamicznych w ocenie dłuższych odcinków dróg.

Słowa kluczowe: bezpieczeństwo ruchu, metody dynamiczne/stacjonarne, oznakowanie poziome, retrorefleksja, widoczność.