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Evaluation of static and dynamic method for measuring retroreflection of road markings

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Preliminary note

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Inadequate and poorly maintained road markings significantly contribute to the occurrence of traffic accidents. Consequently, it is necessary to periodically evaluate the state of road markings by conducting several tests, the most important being the coefficient of retroreflection as determined using the static or dynamic test method. The results of the research conducted in this study show that the dynamic test method provides complete and objective results regarding the quality of road markings, while the static method is somewhat unreliable due to its limitations.

Key words:
road markings, static and dynamic measurement, retroreflection, road safety

Prethodno priopćenje

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Vrednovanje statičke i dinamičke metode ispitivanja retrorefleksije oznaka na kolniku

Neodgovarajuće i slabo održavane oznake na kolniku smatraju se bitnim faktorom koji pridonosi nastanku prometnih nesreća. Upravo je zato nužno periodički ocjenjivati stanje oznaka, što podrazumijeva provođenje nekoliko različitih ispitivanja među kojima je najznačajnije ispitivanje koeficijenta retrorefleksije primjenom statičke ili dinamičke metode. Rezultati istraživanja pokazali su da dinamička mjerna metoda daje cjelovitije i objektivnije rezultate kvalitete oznaka, dok je statička metoda zbog svojih ograničenja u određenoj mjeri nepouzdana.

Ključne riječi:
oznake na kolniku, statičko i dinamičko ispitivanje, retrorefleksija, cestovna sigurnost

Vorherige Mitteilung

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Bewertung der statischen und dynamischen Methode zur Prüfung der Nachtsichtbarkeit von Fahrbahnmarkierungen

Unangemessene und schlecht instand gehaltene Fahrbahnmarkierungen werden als ein bedeutender Faktor angesehen, der zur Entstehung von Verkehrsunfällen beiträgt. Daher ist es sehr wichtig, den Zustand der Markierungen periodisch zu prüfen, was eine Reihe von Untersuchungen umfasst; dabei ist die wichtigste Untersuchung die Prüfung des Koeffizienten der Nachtsichtbarkeit anhand der statischen oder dynamischen Methode. Die Ergebnisse der Untersuchung in dieser Arbeit zeigen, dass die dynamische Messmethode umfassendere und objektivere Ergebnisse der Qualität der Markierungen gibt und dass die statische Methode infolge ihrer Einschränkungen teilweise unzuverlässig ist.

Schlüsselwörter:
Fahrbahnmarkierungen, statische und dynamische Prüfung, Nachtsichtbarkeit, Sicherheit des Straßenverkehrs

1. Introduction

Road markings are an indispensable part of modern roads. They are placed either independently or in combination with traffic signs and signals. As such they constitute an integral segment of construction projects. When constructing a new road or during rehabilitation of an existing one, pavement markings, being highly significant for an overall traffic safety, are considered to be an important element for obtaining the operating permit.
Generally, road markings can be defined as a set of longitudinal and transversal lines, signs, and symbols used on the surface of road infrastructure facilities. Their task is to warn and inform drivers about road condition and about structural characteristics of the road. They also provide guidance to road users and, generally, enable safe operation of traffic [1].
Since driving is a complex task in which the majority of decisions (90 %) are based on visual clues [2], the continuity of road markings along the entire length of the road is a major factor in the driver's process of orientation and overall perception of traffic situation ahead.
During the daytime, drivers perceive road markings mainly by the colour contrast between the road marking and the road surface. However, during the night or in low visibility conditions, the discernibility of road markings is a function of luminous contrast between them and the road surface. This feature is generally enabled by the retroreflection of road markings [3].
Since the requirements for visibility are increasing with a growing share of older drivers on the road, principally regarding sufficient compensation for poorer perception of light, and for longer time the elderly need to react to important visual clues [4], road markings have to be periodically tested to ensure a satisfactory level of visibility. Generally, road markings retroreflection degrades over time under the influence of a number of factors [5]:

- type of material
- road marking position (central or lateral)
- road marking age
- average annual daily traffic (AADT)
- type of road
- number of markings (lines) on the road
- type of asphalt layer on the road
- speed limit
- amount of salt
- quantity of abrasives
- frequency of winter road maintenance activities.

Moreover, scientific research [3, 6] shows that glass beads are likewise an important factor as their quality and quantity directly affect retroflection of road markings. The quality of glass beads depends on their particle size distribution (grading), refractive index, roundness and chemical coating, which enable tighter connection between the beads and the road marking material.
The quality of road markings is evaluated by means of several tests (such as skid resistance, wet and dry film thickness), the most important being the visibility test, i.e. measuring retroreflection of road markings.
The retroreflection of road markings is measured using the static or the dynamic measuring method. Although the static method is, compared to dynamic one, more often used, mainly because of lower price of the equipment, it has several disadvantages such as long duration of testing process, greater disruption of traffic, and possible risk for testing technician given that the tests are conducted on the open road. Additionally, the small measuring range of static retroreflectometers requires a larger number of test sections to obtain precise results along the entire road section. Due to their small measuring range, the static retroreflectometers can not measure retroreflection along the entire width and length of road markings, which might lead to incorrect road marking evaluation results. Namely, moving the static device by less than a centimetre in any direction on the road marking might lead to significantly different measurements. In addition, an experienced technician is able to find places showing high or low retroreflection and thus directly affect the measurement, including the final road marking evaluation results. In contrast, the dynamic test method is characterized by higher initial costs (equipment procurement) and higher measurement costs, but it allows measuring visibility along the entire road section with an instrument that measures retroreflection continuously while driving, which ultimately provides a more complete and objective evaluation of the quality of road markings.
As each of the methods has its advantages and disadvantages, the purpose of this paper is to make a detailed comparative analysis of the retroreflection measurement results conducted on the national roads in Croatia by applying both test methods.

2. Previous research related to retroreflection of road markings

Research activity related to road markings primarily focuses on retroreflection since it is directly connected to the perception of road markings and overall traffic safety. In a field survey conducted on a sample of 65 respondents aged 20–89 years, the authors of [7] studied personal levels of retroreflection necessary for older drivers. The results of the survey showed that more than 85 % of respondents older than 60 years rated 100 mcd/lx/m^2 as the minimum or sufficient value of retroreflection.
The authors Zwahlen and Schnell [8] conducted a study in order to test and confirm the hypothesis that drivers adapt their spatial scanning behaviour and driving speed as a function of visibility of road markings. The results of the study confirmed the hypothesis and the study proposed minimum levels of retroreflection as related to the driving speed limit.
A number of similar studies have been conducted over the years [9-11], all aimed at determining minimum subjective levels of retroreflection for drivers in dry conditions. These studies resulted in the proposed minimum values of retroreflection of 120, 150 and 130–140 mcd/lx/m^2.

In addition to determining minimum required levels of visibility for drivers, the research activities also focused on the retroreflection degradation modelling, in order to estimate durability of road markings. Over the last two decades, various authors developed models [12-5] for predicting sustainability of road markings, aimed at optimizing the road markings maintenance procedures in practical situations. The above considerations show that scientific research has not been addressing specific issues related to testing methodology that directly affects final evaluation of road markings. This mainly concerns maintenance activities and road safety relating to road markings, since studies have shown that the presence of road markings reduces all accidents by 20 % [16] and single-vehicle accidents by 34 % [17].
The main objective of this paper is to analyse the methods for measuring retroreflection of road markings in order to provide new insights that will improve current methodology for estimating quality of road markings.

3. Methodology for testing and evaluating retroreflection of road markings

According to technical requirements of Hrvatske ceste d.o.o. [20], the following tests are conducted in the Republic of Croatia in order to ensure the prescribed quality of road markings:
- preliminary tests or convenience tests
- routine tests
- control tests
- additional control tests
- arbitration tests
- tests prior to the expiry of the defects liability period.

The main objective of road markings tests is to increase the quality and durability of road markings, and thus to improve general road safety while optimizing the costs of application and maintenance.
Convenience tests include tests aimed at proving the convenience or suitability of material intended to be used as road markings, based on the planned type and prescribed quality of road markings.
Routine tests are conducted by the contractor in order to check compliance with the prescribed quality and performance of materials. The tests comprise testing the thickness of wet and dry paint layer, testing daytime and night–time visibility in dry conditions, testing night–time visibility in wet conditions (only for type II road markings) and slip (skid) resistance. Type II road markings are road markings with special properties that are intended to enhance retroreflection characteristics in wet or rainy conditions.
Control tests are provided by the client/employer to determine whether the quality of the road markings system is compliant with the prescribed requirements. The tests comprise:
- control tests before application of road markings that include identification/verification of correspondence (chemical and physical tests) between the road marking samples and the information presented in the corresponding certificates;
- control tests during application/placing of road markings that include: drying time testing, wet and dry coat thickness testing, testing quantity of retroreflective material (glass beads) in the markings, and visual inspection of road markings;
- control tests after placing of road markings that include: testing daytime and night–time visibility in dry conditions, testing night–time visibility in wet conditions (only for type II road markings) and slip (skid) resistance testing, as well as testing the road markings geometry (compliance with design width and length criteria).

Additional control tests are conducted only if limit/boundary values have been obtained during control tests.
Arbitration tests involve repeating the control tests if the employer/client or contractor did not conduct the tests in an appropriate manner. These tests will be conducted by a competent legal entity that did not take part in the disputed tests, or by an entity approved by both parties.
Tests before the expiry of the defects liability period, he employer/client conducts these tests determine the quality of road markings and their compliance with the quality agreed for the duration of the defects liability period. The tests, conducted at least four weeks before the expiry of the said period, include testing daytime and night–time visibility in dry conditions, night–time visibility in wet conditions (only for type II road markings) and slip (skid) resistance.
Daytime and night–time visibility tests for road markings are the most important tests associated with road markings quality evaluation and are performed using either static or dynamic testing method. The daytime visibility (Qd) according to European Standard EN EN 1436:2009 (Materials for Road Markings – Characteristics) represents the road markings visibility observed at an angle of 2.29° at a distance of 30 m under diffuse light, while the night–time visibility or retroreflection (R_L) represents the retroreflection of a light beam from the tested surface at an angle of 2.29°, with a light inlet angle of 1.24° and at a distance of 30 m with low–beam headlights on a vehicle [19].
The static tests are performed in Croatia according to the German method ZTV M02 that has recently been described by Babić et. al. (2016) in [20]. According to this method, the scope of testing depends on the daily performance of the working team that applies the markings, as shown in Table 1. Testing sections are chosen randomly, with five measuring points selected within each of them. For continuous longitudinal markings, the measuring points are set within 100 m sections, and are spaced at equal 25 m intervals, while for intermittent longitudinal markings the measuring points are set in the middle of every other line. The arithmetic mean representing the relevant value of road markings retroreflection is based on five measurements.
When performing the static test, road markings for daytime and night-time visibility are measured using a handheld retroreflectometer as shown in Figure 1.

Table 1. Method for determining testing sections [20]

Length of longitudinal markings applied in one day [km]	Number of testing sections
< 1	1
1 to 5	2
> 5 to 10	3
> 10	4

Figure 1. Measuring (daytime and night-time) visibility of road markings using static retroreflectometer, [21]

The dynamic method for testing retroreflection involves measuring night–time visibility of road markings with a dynamic measuring device along their entire length (Figure 2). The dynamic retroreflectometer is on the right or left side of the vehicle depending on the road marking position. The measuring process includes driving a vehicle along the road, with continuous reading of the retroreflection coefficient of road markings. The greatest advantage of this method is that it tests road markings along their entire length and the device, depending on the measuring interval, provides mean retroreflection values for a specified interval.

Figure 2. Dynamic measurement of road markings night-time visibility

According to technical requirements of Hrvatske ceste d.o.o., the retroreflection values for type I road markings on national roads in Croatia, obtained by any of the two above-mentioned methods, must meet minimum prescribed values specified in Tables 2 and 3, depending on the state of the road marking. Road marking state can be described as "renewed" for new road markings, and "existing" for in–service road markings. This paper does not address type II road markings, which is why their minimum values are not listed.

If the test results are above the value intervals specified in Tables 2 and 3, then the markings meet the requirements. Otherwise, the markings are not considered compliant with the requirements. The second stage of evaluation is conducted if the test results are within the value intervals. Additional 15 test points have to be selected for visibility evaluation to be made in the scope of this second stage of evaluation. The arithmetic mean is calculated based on values measured in the first stage and the second stage of the assessment. If the arithmetic mean is equal to or higher than the minimum requirement specified in Tables 2 and 3, then the road marking is considered acceptable.

Table 2. Minimum retroreflection values for renewed type I lines on national roads in Croatia [20]

Visibility and road condition	Minimum value [mcd/lx/m²]	Interval [mcd/lx/m²]
Night–time visibility, dry road	$R_L \geq 200$	$180 \leq R_L \leq 220$
Daytime visibility, dry road	$Q_d \geq 130$	$110 \leq Q_d \leq 150$

Table 3. Minimum retroreflection values for existing type I lines [20]

Visibility and road condition	Minimum value [mcd/lx/m²]	Interval [mcd/lx/m²]
Night–time visibility, dry road	$R_L \geq 100$	$90 \leq R_L \leq 110$
Daytime visibility, dry road	$Q_d \geq 100$	$90 \leq Q_d \leq 110$

4. Analysis of road markings test results obtained with static and dynamic method

For the purpose of this study, the authors used the results obtained by road markings retroreflection (night–time visibility) tests conducted in 2015 by the Department of Traffic Signalization, Faculty of Transport and Traffic Sciences, University of Zagreb. The centre line retroreflection data were collected on five national roads using the static and the dynamic test method (Table 4). Road markings were measured with the dynamic method, while static measurements were conducted at some locations using the ZTV M02 method. The roads were tested in the period between 30 days and 60 days after application of road markings, according to the *Guidelines and technical requirements for road markings renewal activities* [20]. The dynamic test was conducted with the Zehntner ZDR 6020 dynamic retroreflectometer, while the ZRM 6013+ static retroreflectometer, produced by the same manufacturer, was used for the static test. Both retroreflectometers were calibrated before the measurement, according to the manufacturer's instructions.

Table 4. Roads comprised in the research and the length and number of testing sections

Road	Length of dynamic measurement [km]	Number of testing sections covered by static method
DC28	10,60	4
DC503	16,00	4
DC54	13,25	4
DC207	14,30	4
DC38	20,00	4

Before analysing the methods, it was necessary to establish that the difference between the measurements obtained with the static method and the ones obtained with the dynamic method on the same locations is negligible, and does not affect the final road markings quality evaluation. Table 5 shows the results of these measurements.

The t–test (Two–Sample Assuming Equal Variances) was conducted to statistically examine the difference between the measurements results listed in Table 6. The Kolmogorov–Smirnov test proved that the data are normally distributed and the F–test that the variances are equal, which fulfilled the prerequisites for conducting the t–test. The results of the t–test showed that the arithmetic mean of the measurements obtained by the static method is 235.30 mcd/lx/m^2, and of the measurements attained by the dynamic method 219.05 mcd/lx/m^2, and that there are no significant differences between the two (Table 6).

Table 6. Resultats of t–test

Analysis	R_L_static	R_L_dynamic
Mean	235.30	219.05
Variance	3321.66	3195.27
Observations	19	19
t Stat	0.861080821	
P(T < = t) two-tail	0.394892605	
t Criticaltwo-tail	2.028094001	

The minor differences between the measurements, as previously noted, pertain to the domain of device error and prove the accuracy of both methods, thereby excluding the possibility that an error of a specific type of retroreflectometer will affect the final analysis.

As noted above, the study covered five national roads in the Republic of Croatia. The static and the dynamic retroreflection tests were conducted on the same day. The results obtained with the dynamic method were divided into five value intervals, as shown in Table 7. The Table shows the measured road length for each interval and the percentage share of the intervals in the

Table 5. Static and dynamic retroreflection (night–time visibility) measurements at the same road sections

Road	Chainage	Retroreflection R_L: static method [mcd/lx/m^2]	Retroreflection R_L: dynamic method [mcd/lx/m^2]	Difference in [%]
DC28	1+000	241	229	4.98 %
	3+000	250	231	7.60 %
	7+000	210	189	10.00 %
	9+000	198	185	6.57 %
DC503	2+000	222	202	9.01 %
	4+000	220	194	11.82 %
	8+000	234	218	6.84 %
	10+000	230	217	5.65 %
DC54	2+000	225	204	9.33 %
	7+000	226	211	6.64 %
	10+000	224	204	8.93 %
	12+000	221	212	4.07 %
DC207	1+000	349	336	3.72 %
	5+000	325	310	4.62 %
	9+000	298	280	6.04 %
	13+000	338	313	7.40 %
DC38	3+000	122	105	13.93 %
	9+500	170	162	4.71 %
	15+000	231	225	2.60 %
	18+000	172	164	4.65 %

Table 7. Comparison of results obtained with static and dynamic retroreflection tests

Road	Dynamic test results			Static test results
	Retroreflection interval R_L [mcd/lx/m²]	Percentage share [%]	Average retroreflection value R_L [mcd/lx/m²]	Average retroreflection value R_L [mcd/lx/m²]
DC28	0 - 50	0.00	-	224.75
	50 - 180	20.75	158.55	
	180 - 220	54.25	195.90	
	220 - 300	25.00	243.43	
	> 300	0.00	-	
DC503	0 - 50	0.31	22.40	226.50
	50 - 180	60.31	146.98	
	180 - 220	34.69	193.67	
	220 - 300	4.38	231.00	
	> 300	0.31	308.00	
DC54	0 - 50	0.00	-	224.00
	50 - 180	56.60	141.23	
	180 - 220	40.38	191.63	
	220 - 300	3.02	247.50	
	> 300	0.00	-	
DC207	0 - 50	0.00	-	327.50
	50 - 180	0.00	-	
	180 - 220	0.70	202.00	
	220 - 300	34.62	270.65	
	> 300	64.69	345.98	
DC38	0 - 50	0.00	-	173.75
	50 - 180	8.11	145.58	
	180 - 220	4.46	197.95	
	220 - 300	61.87	262.46	
	> 300	24.95	332.22	

total measurement. Given that the dynamic measuring device measures retroreflection continuously while driving, the testing interval was set to 50 m before the test, which means that the instrument reads an average retroreflection value at every 50 m. The average retroreflection values, as shown in Table 7, represent an arithmetic mean of all average values of 50–meter intervals for every single retroreflection interval.

As the value interval for which the second stage of evaluation needs to be conducted for renewed road markings is between 180 mcd/lx/m² and 220 mcd/lx/m², it can be concluded that none of the values under 180 mcd/lx/m² meet the prescribed quality.

The Table 7 shows that 99.30 % of retroreflection values measured with the dynamic method meet the prescribed values on road DC207. Likewise, the average retroreflection value measured with the static method meets the prescribed values. The values measured with the dynamic method on the road DC28 fail to meet the prescribed requirements in the percentage of 20.75 %, while the ones measured with the static method meet the requirements. Similarly, on the roads DC503 and DC54, 60.62 % and 56.60 % of road markings measured with the dynamic method fail to meet the requirements, while the results of the static method show that the markings meet the prescribed quality. It is important to note that on the mentioned roads, a significant proportion of road markings retroreflection values, determined according to the dynamic method, range from 180 to 220 mcd/lx/m², which shows that the road markings quality is unsatisfactory.

Road markings on the road DC38 meet the requirements (86.82 %) according to the results of the dynamic method. However, they fail to meet the requirements according to the static method.

Table 8 shows the final road markings quality evaluation, according to the results obtained during the testing.

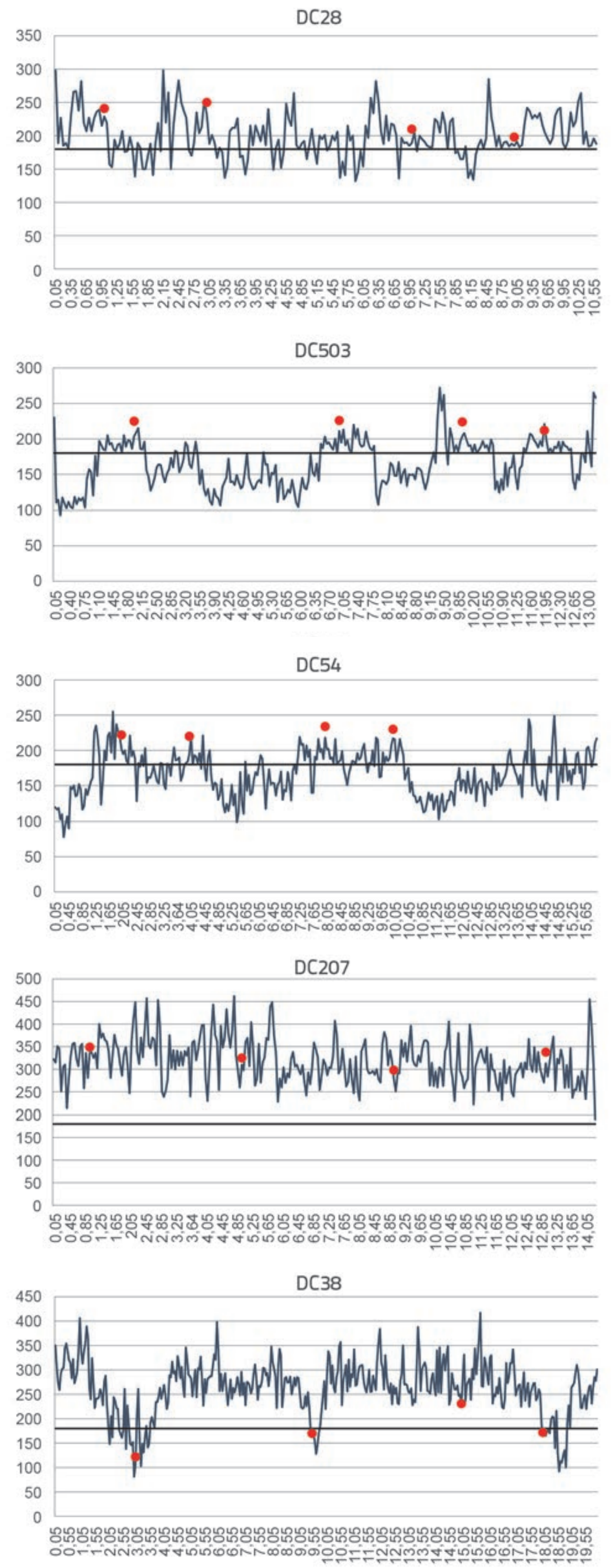

Figure 3. Graphic representation of dynamic and static test results on analysed roads

Table 8. Quality evaluation of road markings retroreflection, depending on the test method

Road	Road marking quality meets the prescribed requirements acc.to the dynamic method	Road marking quality meets the prescribed requirements acc.to the static method
DC28	NO	YES
DC503	NO	YES
DC54	NO	YES
DC207	YES	YES
DC38	YES	NO

Graphical representation of results is shown in Figure 3. The x–axis indicates the length of road in km, and the y–axis shows retroreflection of road markings. The black horizontal line represents the minimum prescribed retroreflection value (180 mcd/lx/m^2). The blue line represents retroreflection values obtained with the dynamic method, while the red dots represent retroreflection values achieved with the static method (according to ZTV M02 method).

5. Conclusion

The results obtained in the scope of this study show that a different interpretation and road markings quality evaluation is possible, depending on the method used in retroreflection measurements. Different interpretation is due to the difference in test procedure. In static testing, the test involves only randomly chosen road sections that are relatively short and comprise a small part of the road. If the roads used in this study are taken as an example, it is easy to calculate the percentage of the road covered by the static test. Namely, the total length of the five roads amounts to 74.15 km. Four testing sections, each 100 m long, are tested for each road according to ZTV M02 method, which means that the test includes 400 m of each road. In other words, by observing the total length of all the roads, only 2.69 % of their length was tested with the static method.
The analysis of the obtained results shows that, according to the static method, road DC38 fails to meet the requirements, which would inflict direct damage to the road markings contractor, since it would have to renew the road markings at its expense. The road markings quality on DC503 and DC54, measured according to the static method, meets the requirements although, according to the dynamic test results, 60.62 % and 56.60 % of markings fail to meet the prescribed requirements, which would directly damage relevant road authorities. According to the dynamic method, road DC28 fails to comply with the demands in the share of 20.70 %, while according to the static method it meets the minimum requirements. However, according to the dynamic method, no less than 54.28 % of the section lies in the value interval between 180 mcd/lx/m^2 and 220 mcd/lx/m^2, which shows that the quality of road markings is unsatisfactory.

Based on the overall pass/fail grade presented in Table 8, it can be concluded that the differences, i.e. incorrect evaluations of road markings based on static measurement results, come from their main shortcomings. Namely, due to their small measuring range, static retroreflectometers fail to measure retroreflection along the entire width and length of road markings. The measuring range of Zehntner ZRM 6013+ static retroreflectometer is 52 mm x 218 mm. Thus, moving the static device by less than a centimetre in any direction along the road marking might lead to significantly different measurements. Due to the need for manual measurements, the static method also significantly depends on the controller/technician. An experienced controller might find places showing high or low retroreflection values which would directly affect the measurement, including the final road marking evaluation results. Also, only a small part of the road is covered by the static method (2.69 % of the total road length in this study), which might lead to an incorrect evaluation, as shown by this study.

On the other hand, the dynamic tests comprised 100 % of road markings length, and due to the greater measuring surface (for Zehntner ZDR 6020 it amounts to more than 1000×880 mm), every centimetre of road markings was measured, ultimately providing a more detailed and objective evaluation of the quality of road markings. For this reason, the use the dynamic method is recommended. However, despite its limitations, the static method has some advantages over the dynamic method, and the authors would recommend it for shorter road marking quality inspections, which do not require an evaluation of all road markings.

Based on the results of this study, an additional research is recommended in order to improve the methodology of the static method. With more extensive research, it might be possible to determine how many measuring sections would be needed, and what would be their optimal length, to approach the precision of the dynamic method and to propose, on this basis, further improvements of the static methodology.

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