DETERMINING THE CORRELATION BETWEEN DAYTIME AND NIGHT-TIME ROAD MARKINGS VISIBILITY

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Abstract. Road markings quality control implies conducting several different tests, of which the most significant are visibility tests comprising daytime and night-time visibility measurements by applying the static or the dynamic measuring method. Although the dynamic test method allows measuring the visibility along the entire road section and thus provides a more complete and objective evaluation of road markings quality compared to the static method, it does not measure daytime visibility, for which both the European and the national directives define the minimum requirements. The purpose of this paper is to examine the correlation between daytime and night-time visibility based on static measurements conducted on state roads in the Republic of Croatia. The correlation analysis determined that the strength of relationship between daytime and night-time visibility, is relatively weak. Despite being relatively weak, the relationship still exists, which was the reason for conducting a further analysis. In the analysis, a unique coefficient was obtained through the ratio of retroreflection value and daytime visibility value for all the measurements. The unique coefficient was basis for development of a model that will be able to calculate the daytime visibility based on the results of the dynamic measurements of road markings night-time visibility. The authors evaluated the model with a *t*-test and concluded that the accuracy of the model is statistically satisfactory.

Keywords: daytime and night-time visibility, retroreflection, road asset management, road markings, road safety, static and dynamic measurement.

1. Introduction

Road markings form the road surface by combining lines, signs and symbols thus providing warning, guidance and information to road users and regulating road traffic, with the purpose of increasing road safety. Since they are positioned in the driver central field of vision, road markings are one of the most important components of traffic control plan whose presence might generally reduce all accidents by 20% (Miller 1992).

When driving, drivers constantly interact with the environment and visual stimuli cause almost 90% of decisions made while driving (Thurston 2009). With a growing share of older drivers on the road, the requirements for visibility of all traffic infrastructure elements, including road markings, increase as well (Eby *et al.* 2008). Accordingly, the visibility is the main feature of road markings, both during daytime and night-time.

The Q_d coefficient expresses daytime visibility and represents the value of diffuse scattered light received by the observer. The R_L coefficient expresses night-time visibility or retroreflection and represents the luminous intensity from a road marking when illuminated with low-beam headlights of a vehicle.

The road markings quality, and hence, their visibility depends on several factors (Shahata *et al.* 2008):

– type of material;
– road marking position (central or edge);
– road marking age;
– Annual Average Daily Traffic (AADT);
– type of road;
– number of markings (lines) on the road;
– type of asphalt layer on the road;
– speed limits;
– the amount of salt;
– the amount of abrasives;
– the amount of winter maintenance activities on the road.

According to scientific research by Grosges (2008), Guanghua *et al.* (2010) and Babić *et al.* (2015), glass beads as retroreflective material also present an important factor whose quality and quantity directly affect the road markings visibility, or retroreflection.

In order to fulfil their function and increase traffic safety, road markings should be renewed and maintained in a timely manner. Road markings quality control implies conducting several different tests, of which the most significant are road markings visibility tests, comprising daytime and night-time visibility measurements by means of static or dynamic test method.

The static method includes using hand-held measuring device, which is manually set on the markings and measures the daytime and night-time visibility. The main disadvantages of this method relate to the long duration of the test process, greater disruption of traffic and possible risk for the controller given that the tests are conducted on the open road. Additionally, the small measuring range of static retroreflectometers requires a larger number of measurement sections in order to obtain systematic results along the entire road section.

On the other hand, the dynamic method includes only measuring the markings night-time visibility by using a dynamic retroreflectometer mounted on the vehicle (on the right side for edge markings, on the left side for central markings) which measures road markings retroreflection while driving. The main disadvantages of this method are the price of the dynamic retroreflectometer and additional equipment (computers, software, etc.) and the costs of maintenance and training of controllers. However, compared to the hand-held retroreflectometers, the main advantages of the dynamic ones are faster testing of longer sections and faster collection of a large amount of data, which is important for the objective evaluation of road markings quality. Furthermore, the dynamic retroreflectometers have greater measuring area compared to the static ones (approximately 77 times more, depending on individual characteristics of static retroreflectometer), so during the measurements they comprise the entire marking, as opposed to the hand-held retroreflectometers, which measure only a smaller part of the marking. Additionally, since the dynamic retroreflectometers are mounted on the vehicle, traffic disruption is negligible and the safety of the controller is higher.

Given the many advantages of the dynamic method, including its objectivity and integrity when evaluating the road markings, it represents a contemporary method for testing road markings retroreflection. However, the dynamic retroreflectometers available on the market do not measure daytime visibility, for which both the European and the national directives define the minimum requirements.

The purpose of this paper is to examine and test the correlation between road markings daytime and night-time visibility based on the results of static measurements and to develop a model, which will enable daytime visibility prediction based on the markings night-time visibility measured by the dynamic method. The developed model might help road authorities efficiently evaluate the quality of road markings.

2. Short overview of previous research

There have been numerous scientific activities on this subject given the fact that road markings are important elements of traffic safety. Previous research has focused on examining road markings retroreflection, i.e. their night-time visibility since in reduced visibility conditions (night-time, twilight, poor weather conditions, etc.) drivers largely depend on the information received from the traffic signalization, including road markings.

A number of authors, as presented in Table 1, examined the minimum subjective levels of retroreflection for drivers in dry and wet conditions. In these studies, participants were interviewed to provide their subjective evaluation of road markings retroreflection in order to determine the minimum subjective levels of retroreflection. The obtained results from the interviewers and the results of quantitative retroreflection measurements were compared.

In addition, a number of studies focused on predicting road markings service life or durability which has a direct influence on their visibility and the road markings renewal activities, and thus on the overall costs of maintenance. The durability of road markings measured by determining the percentage of material remaining on the road surface or

Table 1. Current research related to determining the minimum levels of retroreflection

Author	Year	Road conditions	Methodology	Results
Graham *et al.*	1996	Dry	Subjective evaluations and quantitative measures	Minimal retroreflection: 100 mcd/lx/m^2.
Loetterle *et al.*	2000	Dry	Subjective evaluations and quantitative measures	Minimal retroreflection: 80–120 mcd/lx/m^2.
Parker *et al.*	2003	Dry	Subjective evaluations and quantitative measures	Minimal retroreflection: – 80–130 mcd/lx/m^2 for drivers younger than 55 years; – 120–65 mcd/lx/m^2 for drivers older than 55 years.
Debaillon *et al.*	2007	Dry	Pavement Marking Visibility Module	Minimal retroreflection: – 40–90 mcd/lx/m^2 for fully marked roadways; – 90–575 mcd/lx/m^2 for roadways with only centre lines.
Gibbons *et al.*	2012	Wet	Subjective evaluations and quantitative measures under simulated rain conditions	Minimal retroreflection: 150 mcd/m^2/lx for 64.37 km/h.

indirectly by testing the bonding strength between the material and the road surface (Migletz *et al.* 1994).

Since the 1990s, various authors have developed a number of models for predicting the durability of road markings as presented in Table 2. Different models used models used different variables based on which the degradation of retroreflection of different materials was described. Table 2 presents most significant methodologies and results.

There are not too many conducted studies to address shortcomings of road markings visibility test methods and methodologies in the literature. Since the dynamic retro-reflectometers available on the market measure only the night-time visibility, it is necessary to conduct additional daytime visibility tests since the European and the national directives define the minimum levels of daytime visibility. For this reason, the purpose of this study is to eliminate the aforementioned shortcoming of the dynamic method.

3. Testing and evaluation methodology for road markings retroreflection in Croatia

Quality assessment of applied road markings based on the test results. The application of different test methods and procedures and constant inspection of road markings enables achieving a high level of quality, i.e. ensuring that road markings always have a satisfactory level of retroreflection, which consequently improves the road safety.

In the Republic of Croatia, according to the technical requirements of *Hrvatske ceste d.o.o.* (Guidelines and technical requirements for performing works on road markings renewal), the tests conducted in order to ensure the prescribed quality of road markings comprise:

– convenience tests;
– ongoing tests;
– control tests;
– additional control tests;
– arbitrary tests;
– tests prior to the expiry of the warranty.

Convenience tests include tests aimed at proving the convenience or suitability of a material intended to be used for applying road markings, based on the foretold type of marking and prescribed quality.

Ongoing tests, conducted by the Works Contractor, determine the prescribed quality of material and works performance. 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 – road markings with special properties intended to enhance the retroreflection in wet or rainy conditions) and slip resistance.

Control tests, ensured by the Employer, determine whether the quality of the road markings system is compliant with the prescribed requirements. The said tests comprise:
– control tests prior to the application of road markings which include identification, that is, verification of compliance (chemical and physical tests) between the delivered samples of the road markings material and the information presented in the certificates;
– control tests during the application of road markings which include testing the drying time, the thickness of wet and dry layer, the quantity of

Table 2. Literature review related to modelling the durability of road markings

Author	Year	Model	Material	Variables	R^2
Andrady	1997	Logarithmic	Thermoplastic	Initial retroreflection	N/A
Perrin *et al.*	1998	Exponential	Tapes, paint, epoxy	Time, initial retroreflection, minimum acceptable retroreflection, average deterioration rate	0.58 for tapes; 0.005 for paints; 0.03 for epoxy
Lee *et al.*	1999	Linear	Paint, thermoplastic	Time	0.14
Migletz *et al.*	2001	Linear, exponential, squared	Paint, thermoplastic, epoxy	Time, the cumulative number of vehicles passing	N/A
Abboud, Bowman	2002	Logarithmic	Paint, thermoplastic	Time, AADT	0.31 for paints 0.58 for thermoplastic
Sarasua *et al.*	2003	Complex curve with a Linear region	Thermoplastic, epoxy	Time, colour of the markings, type of the road pavement	N/A
Kopf	2004	Linear	Paint, thermoplastic	Time	N/A
Zhang, Wu	2005	"Smoothing spline" and "time series"	Paint, thermoplastic, tapes	Time	N/A
Fitch, Ahearn	2007	Logarithmic	Polyurea	Time, application time, AADT	0.53−0.86
Sitzabee	2009	Linear	Paint, thermoplastic	Time, initial retroreflection, AADT, colour and location of the markings	0.60 for thermoplastic 0.75 for paints

retroreflective material (glass beads) in the material and visual inspection of road markings;

– control tests on applied road markings which 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 resistance, as well as testing the road markings geometry in terms of designed road markings width and length.

Additional control tests are conducted only if control tests on applied road markings resulted in limit values.

Arbitrary tests involve repeating the control tests, if the Employer or the Contractor did not conduct the tests appropriately. An authorized legal entity which has not taken part in the disputed tests or which has been approved by both parties conducts the tests in order to determine the quality of applied road markings and its compliance with the quality agreed for the duration of the warranty period. The Employer conducts tests prior to the expiry of the warranty. The tests, conducted at least four weeks before the expiry of the warranty, include testing daytime and night-time visibility in dry conditions, night-time visibility in wet conditions (only for type II road markings) and slip resistance.

One of the most important elements when testing road markings quality is testing road markings daytime and night-time visibility. As previously mentioned, there are two ways to conduct the tests:

– by using the static method for testing road markings visibility (daytime and night-time visibility);
– by using the dynamic method for testing road markings visibility (night-time visibility).

As stated before, the daytime visibility (Q_d) represents road markings visibility observed under 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 (*EN 1436:2009 Road Marking Materials. Road Marking Performance for Road Users*).

The static tests on road markings are performed with hand-held retroreflectometers according to the European standard *EN 1436:2009*. The standard describes the basic measuring equipment, standard measuring condition of measuring equipment, practical applications and calibration of measuring equipment, uncertainty of measurement and conditions of wetness and rain in which night-time visibility of road markings is measured.

On the other hand, the standard does not prescribe how many sections of a road should be measured, the length of these sections and the number of measuring points. Accordingly, it does not prescribe a detailed methodology for conducting the measurement.

For this reason, the static tests are performed in Croatia according to the German *ZTV M02* (*Additional Technical Conditions of Contract and Guidelines for Road Markings*) method, which provides a detailed methodology for conducting the measurement. According to *ZTV M02*, the scope of testing depends on the daily performance of the working team that applied the markings, as shown in Table 3.

Testing section is defined as follows:

– for continuous longitudinal lines – section 100 m long
– for intermittent longitudinal lines – section comprising 10 lengths of intermittent line

Testing sections are chosen randomly, with five measuring points being selected within each of them. For continuous longitudinal markings the measuring points are allocated at a distance of 100 m at equal intervals (start, 25 m, 50 m, 75 m and 100 m), while for intermittent longitudinal markings the measuring points are allocated in the middle of every other line. The arithmetic mean, that represents the relevant value of road markings retroreflection, is formed of five measured values. Figure 1 shows the test principle according to *ZTV M02* method (static method).

The dynamic method for testing retroreflection involves measuring the road markings night-time visibility with a dynamic measuring device along their entire length. The dynamic measuring device is on the right or left side of the vehicle depending on the road marking position (Fig. 2). The measuring process includes a vehicle driving on the road and reading the retroreflection coefficient of road markings. The length of the measuring interval in which the device will measure the mean values of a certain measuring section (25 m, 50 m or 100 m) is selected before the measurement. While driving, care should be taken that the road markings being measured are always within the measuring zone, which is for most dynamic retroreflectometers around 50×100 cm. The greatest advantage of this method is that it tests road markings in their entire length and the device, depending on the

Table 3. Method for determining testing sections according to *Hrvatske ceste d.o.o.*

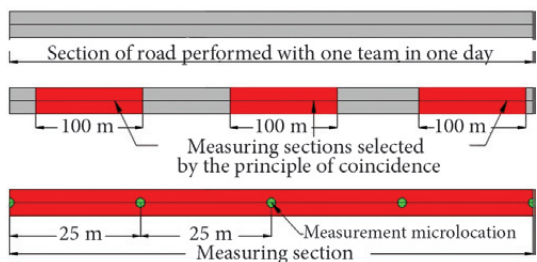| Length of longitudinal markings applied in one day, km	Number of testing sections
<1	1
1 to 5	2
>5 to 10	3
>10	4

Fig. 1. Measurement principle according to *ZTV M 02* (static method)

measuring interval, provides mean retroreflection values of a certain interval.

The results of road markings visibility tests must meet the minimum prescribed values specified in Table 4. If the test results, depending on the state of the line (renewed or existing), are above the value intervals specified in Table 4 then the marking meets the requirements, otherwise the marking does not comply with the requirements. The second stage of evaluation occurs if the test results are within the value intervals specified in the Table 4. An additional 15 test points for visibility evaluation need to be selected for each testing section that must be controlled in the second stage of evaluation. The arithmetic mean is calculated based on measured values of all the test points in the first stage and the second stage of evaluation. If the arithmetic mean is equal to or higher than the minimum requirement specified in Table 4, then the road marking is acceptable.

When comparing the two test methods for road markings visibility, it is evident that the dynamic method represents a modern, objective and comprehensive approach to testing and evaluating the road markings quality. The disadvantage of this method, in addition to high initial costs for equipment supply and maintenance, is that it does not measure the road markings daytime visibility. Even though night-time visibility has high importance for traffic safety, it is necessary to conduct daytime visibility tests since the European and the national directives defined the minimum requirements of daytime visibility.

According to the explained disadvantage, the purpose of this paper is to develop a model that allows calculation of the daytime visibility based on the results of dynamic measurements of the road markings night-time visibility.

4. Results and discussion

The authors of the study used the results of the road markings static tests conducted in the period from 2012 to 2014 in order to determine the correlation between the road markings daytime and night-time visibility. The Department of Traffic Signalling, Faculty of Transport and Traffic Sciences, University of Zagreb conducted the measurements of daytime and night-time visibility, and included the state roads in Osijek-Baranja County, Sisak-Moslavina County and Bjelovar-Bilogora County in the Republic of Croatia.

The static tests, according to the European standard *EN 1436:2009* and the technical requirements of *Hrvatske ceste d.o.o.,* by using *ZTV M02* method were conducted.

The total of 1182 measurements was conducted in the three years of research on the visibility of the left, right and centre line separately.

The statistical software SPSS was used to process the obtained data. The purpose of the study was to examine the correlation between the daytime and night-time visibility of road markings. In order to determine which correlation test to perform (parametric or nonparametric), the normality of the data distribution and homogeneity of

samples were analysed. Q-Q plots were used given the size of the sample for determining the normality of data distribution. Figure 3 shows normal data distribution of Q-Q plots for the daytime and night-time visibility. Furthermore, the data used in the analysis are normally distributed according to the application of the central limit theorem, which states that the sampling distribution of the mean of any independent, random variable will be normal or nearly normal, if the sample size is large enough.

Fig. 2. Measuring vehicle with dynamic retroreflectometer

Table 4. Minimum values of visibility for type I markings according to *Hrvatske ceste d.o.o* on dry road surface

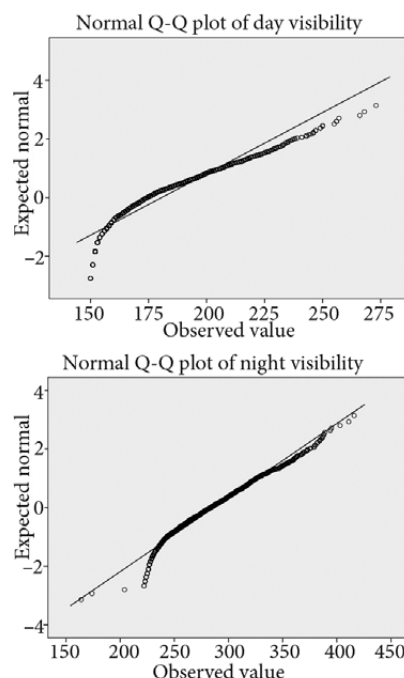| Visibility	Type I markings	Value	
		Minimum	Interval
		mcd/lx/m^2	
Night-time	Existing	$R_L \geq 100$	$90 \leq R_L \leq 110$
	Renewed	$R_L \geq 200$	$180 \leq R_L \leq 220$
Daytime	Existing	$Q_d \geq 100$	$90 \leq Q_d \leq 110$
	Renewed	$Q_d \geq 130$	$110 \leq Q_d \leq 150$

Fig. 3. Q-Q plots for daytime and night-time visibility

Table 5 presents the mean, minimal and maximal value of measured daytime and night-time visibilities and standard deviations between the daytime and night-time visibility for 1182 measurements.

After conducted the normality test, the homogeneity of samples (both for daytime and night-time visibility) was tested. The significant value of both variables is less than 0.05 (for Q_d Sig. = 0.000 and for R_L Sig. = 0.018) which indicates that the samples are not homogenous. Therefore, the nonparametric Spearman test was used to determine the correlation between daytime and night-time visibility.

The correlation analysis determined that the Spearman correlation coefficient = 0.353, showing that the strength of relationship between variables is relatively weak (Table 6).

The relatively weak correlation coefficient is the result of several relevant factors. The night-time visibility of road markings directly relates to the retroreflective material, or glass beads. The type of beads, their quality that is reflected in the roundness, gradation and refractive index, immersion of glass bead into the material, type of

Table 5. Mean visibility value and mean deviations between the daytime and night-time visibility

Visibility, mcd/lx/m^2	Mean value	Standard deviation	Measured value	
			Minimum	Maximum
Daytime Q_d	180.62	23.89	150	273
Night-time R_L	286.48	39.58	164	416

Table 6. Results of Spearman correlation between daytime and night-time visibility

Visibility	Daytime	Night-time	Spearman Correlation
Daytime	1.000	.353**	Correlation Coefficient
	.	.000	Sig. (two-tailed)
	1182	1182	Number of samples
Night-time	.353**	1.000	Correlation Coefficient
	.000	.	Sig. (two-tailed)
	1182	1182	Number of samples

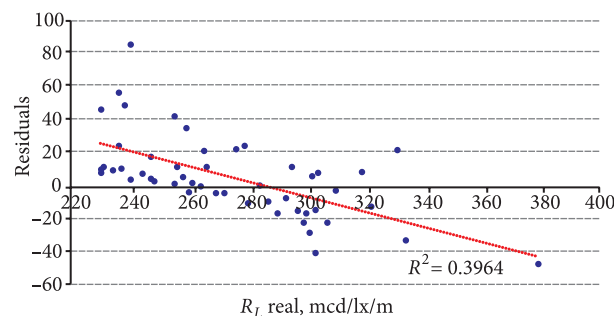*Note:* **correlation is significant at the 0.01 level (two-tailed).

Fig. 4. Residual plot of difference between real and daytime visibility obtained from a model

chemical coating which enables connection between the beads and the material and the quantity of beads directly affect the road markings retroreflection. Certainly, a number of external factors such AADT, maintenance activities on winter roads, type of road, etc. will also influence the road markings retroreflection degradation, but the above factors are those that are exclusively related to the retroreflective elements.

As previously explained, daytime visibility represents the value of diffuse scattered light received by the observer, which means it measures the brightness of a road marking as seen in typical or average daylight or under road lighting.

Although the correlation between the daytime and night-time visibility is relatively weak, it still exists and for this reason, further analysis obtained a unique coefficient through the ratio of retroreflection value and daytime visibility value for 1182 measurements. The obtained unique coefficient enabled to attain a model for the calculation of the daytime visibility, as presented in Eq (1):

$$Q_d = \frac{R_L}{K} \pm AD, \qquad (1)$$

where Q_d – daytime visibility, mcd/lx/m^2; R_L – night-time visibility, mcd/lx/m^2; K – mean value of unique coefficient of daytime and night-time visibility ratio $K = \frac{R_L}{Q_d}$; AD – average absolute deviation of daytime visibility, mcd/lx/m^2.

The final model includes the mean unique coefficient, which amounts to 1.60 and the mean absolute deviation, as presented in Eq (2):

$$Q_d = \frac{R_L}{1.60} \pm 20.63. \qquad (2)$$

In order to evaluate the obtained model, the conducted statistical analysis consisted of two parts. In the first part, the static test method collected 50 measurements of daytime and night-time visibility. In the second part, by using the model presented in Expression (2) based on the night-time visibility obtained in the first part of the evaluation, the road markings daytime visibility values were calculated (Q_d model). The average absolute value of residuals is 18.14 mcd/lx/m^2. The Root-Mean-Square Error (RMSE) measured the differences between the values predicted by the model and the values of measured daytime visibility. RMSE for this test sample amounts to 24.93 mcd/lx/m^2, which is satisfactory because the measured daytime visibility ranges from 150 mcd/lx/m^2 to 237 mcd/lx/m^2.

The residual plot in Fig. 4 shows that the residuals (difference between real and daytime visibility obtained from a model) are mostly located in range from +20 to –20 from the x-axis. There are some extremes which occur when the real daytime visibility is more than 180 mcd/lx/m^2 and they affect the general accuracy of the model which is $R^2 = 0.3964$. Although the accuracy of the model is not precise enough, the model shows that the majority of residuals are located above the x-axis, which means that for those

points prediction value of the model was lower than the real measured value. Accordingly, if the predicted daytime visibility value is passing the minimal prescribed values in Table 4 the real daytime visibility should pass as well.

For further evaluation, a *t*-test: Two sample Assuming Equal Variances (after having conducted the *F*-test for testing the variances, it was concluded that the variances of daytime and night-time visibility are equal) was used. The hypothesis *H*0 states that there is no statistically significant difference between the actual values and values of daytime visibility obtained by the model, while the hypothesis *H*1 states that a statistically significant difference between the stated values exists. The significance level (α) has been set to a value of 0.05. In the analysis, the authors used 50 samples, and based on the central limit theorem it was assumed that the data distribution was normal.

The *t*-test results (Table 7) showed that $P(T \leq t)$ two-tail > 0.05, which confirms the hypothesis *H*0, stating that there is no statistically significant difference between the actual road markings daytime visibility and the daytime visibility obtained by the model.

5. Conclusions

1. There are not many scientific activities sufficiently focused on solving certain shortcomings of road markings visibility test methods and methodologies in the literature. Road markings visibility test are conducted in two ways: by using the static and by using the dynamic test method. When comparing the two methods, the dynamic method represents a modern, objective and comprehensive approach to testing and evaluating the road markings quality. The disadvantage of this method, in addition to high initial costs for equipment supply and maintenance, is that it does not measure the road markings daytime visibility. Even though night-time visibility has high importance for traffic safety, it is necessary to conduct daytime visibility tests since the European and the national directives defined the minimum requirements of daytime visibility. Furthermore, the daytime visibility becomes even more important with the advent of autonomous cars, which are using road markings for positioning of the car on the road.

2. The purpose of the study is to eliminate the stated shortcoming by developing a model, which will be able to calculate the daytime visibility based on the dynamic measurements of the road markings night-time visibility. For this purpose, 1182 measurements of daytime and night-time visibility have been collected by using the static test method in the period from 2012 to 2014. Even though the correlation analysis showed a relatively weak correlation between the daytime and night-time visibility (Spearman correlation coefficient 0.353), by conducting further analysis a model was developed to predict the road markings daytime visibility based on night-time visibility. The model was evaluated using 50 measurements that have not been previously used to develop the model and showed an accuracy of $R^2 = 0.3964$. Due to the wide range of real daytime visibility values (from 150 mcd/lx/m² to 237 mcd/lx/m²) which causes extremes, a *t*-test) was conducted. According

Table 7. *t*-test results

Analysis	Q_d_actual	Q_d_model
Mean	177.88	171.2875
Variance	386.3526531	432.2929
Observations	50	50
Hypothesized Mean Difference	0	
Degrees of freedom	98	
t Stat	1.629247976	
$P(T \leq t)$ two-tail	0.106470944	
t critical two-tail	1.984467455	

to the results of the *t*-test, it was concluded that the model accuracy is statistically satisfactory.

3. The results obtained in this study represent significant insights, which are vital for the improvement of the road markings dynamic testing methodology. As mentioned earlier, the dynamic testing of road markings visibility does not include measuring the daytime visibility. The developed model, even with shortcomings, eliminates to a certain extent this disadvantage. By using the model, road authorities can predict daytime visibility based on night-time visibility values measured with the dynamic method without conducting further measurements.

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