Retroreflection Performance of Urban Road Signs

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Abstract

The objective of this paper is the investigation of the reflectivity of vertical signs located in urban roads. Real data from field measurements at selected avenues in Athens prefecture were collected, utilizing specific instruments that were able to measure the coefficient of retroreflection. In order to collect an adequate number of data, retroreflection was also measured in signs of the minor roads. The linear regression modelling approach for predicting the retroreflection of each sign colour was found efficient and may be useful to researchers and practitioners aiming to evaluate and standardize the sign reflectivity. As a result, it is feasible to examine how the characteristics of vertical road signs can affect the retroreflection value, such as age and orientation. During the data analysis, seven linear prediction models were developed, regarding the type and colour of vertical signs. The analysis results show that the age significantly affects the retroreflection of vertical signs whereas the orientation was found to have a smaller influence on the reflectivity values.

Keywords: Retroreflection, Traffic Signs, Linear Regression

1. Introduction

Road signs are a determining factor of the road network in terms of safety and traffic flow. The role of road signs is vital as it helps to prevent accidents by transmitting messages to users (drivers and pedestrians). Its purpose is to immediately inform users about the conditions of the road environment, ensuring their safety. In particular, it warns of dangers that may exist in various sections of the road network, informs about the geometric characteristics of the road, guides the driver and regulates traffic.

The necessity of vertical signage is very important, as it informs users about the road environment. In order for drivers to be able to receive sign messages, the signs must either be illuminated by an external light source or to be constructed by materials that have certain reflective properties. These reflective properties allow light from vehicle's headlights to be reflected back to the source so that the driver can read and interpret sign messages during night-time. One of the key parameters that addresses the adequacy of road signs in terms of enhancing users' safety and visibility is their retroreflection level.

2. Methodology

By incorporating signs made of retroreflective material, even if they are not illuminated by external lights are still visible at night. Retroreflection works by redirecting light from the sign back to the source. Retroreflectivity, RA, is the amount of light reflected off a surface from a source to an observer, measured by the units of candelas per lux per square meter (cd/lux/m2).

The European Standard EN 12899-1 has been prepared by the European Commission and the European Free Trade Association [1]. This EN 12899-1 standard contains test methods and requirements of the materials of road signs. EN 12899-1 standard describes 3 types of retroreflective materials that can be used on traffic signs, categorized into three categories: Engineering Grade (Type I), Diamond Grade (Type II) and High Intensity (Type III). The most commonly used retroreflective sheeting material for traffic sings in urban roads is Diamond Grade (Type II) [1,2].

The reflective area of the sign plate should have at least the minimum values of the retroreflection coefficient expressed in candelas per lux per square meter (cd/lux/m²), when is illuminated with a CIE Standard Illuminant A and measured as recommended by International Commission on Illumination (CIE), with specific lighting angles (βi) and observation angles (αi).

The following tables indicate the retroreflection coefficient angles in relation to lighting and observation angles as well as the colour of the Standard Illuminant CIE for type I and II reflectiveness according to the European Standards EN-12899.

Table 1: Coefficient of retroreflection R' for Type I [1,2]

Geometry of measurements		Colour							
α	β_1 ($\beta_2 = 0$)	White	Yellow	Red	Green	Blue	Brown	Orange	Grey
12'	+5°	70	50	14,5	9	4	1	25	42
	+30°	30	22	6	3,5	1,7	0,3	10	18
	+40°	10	7	2	1,5	0,5	#	2,2	6
20'	+5°	50	35	10	7	2	0,6	20	30
	+30°	24	16	4	3	1	0,2	8	14,4
	+40°	9	6	1,8	1,2	#	#	2,2	5,4
2°	+5°	5	3	1	0,5	#	#	1,2	3
	+30°	2,5	1,5	0,5	0,3	#	#	0,5	1,5
	+40°	1,5	1,0	0,5	0,2	#	#	#	0,9

Table 2: Coefficient of retroreflection R' for type II [1,2]

Geometry of measurements		Colour								
α	β_1 (β_2 = 0)	White	Yellow	Red	Green	Dark green	Blue	Brown	Orange	Grey
12'	+5°	250	170	45	45	20	20	12	100	125
	+30°	150	100	25	25	15	11	8,5	60	75
	+40°	110	70	15	12	6	8	5,0	29	55
20'	+5°	180	120	25	21	14	14	8	65	90
	+30°	100	70	14	12	11	8	5	40	50
	+40°	95	60	13	11	5	7	3	20	47
2°	+5°	5	3	1	0,5	0,5	0,2	0,2	1,5	2,5
	+30°	2,5	1,5	0,4	0,3	0,3	#	#	1	1,2
	+40°	1,5	1,0	0,3	0,2	0,2	#	#	#	0,7

3. Data Collection

Data Collection was conducted utilizing a portable retro reflectometer device (Retrosign GR3), in order to assess the visibility levels of the examined road traffic signs [3]. The RetroSign GR3 model illuminates the sign at a +5º entrance angle, with the angle of observation being 0.33º. In order to have accurate results during the measurements, the retroreflectometer should be held vertical and stable against traffic signs.

The procedure involves measurements taken from four different areas of the signs for each different color. The average of the four recorded measurements was used in order to determine the retroreflection coefficient that was taken into account during the analysis process. Figure 1 below indicates the previous mentioned procedure within a STOP type regulatory sign.

Figure 1: Retroreflection measurement points for STOP road sign.

As far as the accuracy of measurements is concerned, it was decided to examine road signs that were installed in two major urban arterials located at the Athens city centre and Athens coastal zone (Vasilissis Sofias and Poseidonos Avenues accordingly). These specific avenues were selected due to their noticeable exposure to traffic congestion especially during the peak times. The road signs of the latter avenue (Poseidonos Avenue) were investigated as buildings are located only on the one side of the road. These signs are found to be exposed to solar radiation a far longer period during daylight conditions. In order to assess the orientation of the road signs, a number of minor side roads for both arterials were also examined.

The reflectivity measurements, as well as some specific characteristics that heavily affect the road signs were recorded simultaneously during the field measurements. These are the followings:

- Type and code of road sign (warning, regulatory, guide signs).
- Installation date (year): The construction and installation year is indicated at the back side of each road sign.
- Orientation (north, east, south, west): The orientation of each road sign was determined with the use of a compass (or with the internal compass of Google maps).
- Material (Type I, II and III) [1,2]. For this characteristic it was assumed that all the examined road signs were of Type II, as this appeared to be an important requirement for the most of the examined signs.

For the purposes of assessing the existing condition of the vertical signage within the urban road network, damages in relation to vandalisms were also recorded during the field measurements.
The presentation of the field measurements is performed with the use of bar plots in order to visualize the results and conduct conclusions. The graphs depict the retroreflection level represented by the coefficient of retroreflection (R') of each sign type in relation to their installation date. Data collection involved measurements, taken from all three above mentioned sign types (Warning, Regulatory and Informative signs) in the examined arterials.

Below three indicative bar plots are presented that show how the installation date influences the coefficient of retroreflection, for all the examined colour types (white, red, blue and yellow). Dashed lines denote the minimum limit of the retroreflection coefficient (R') for each colour of the sign according to EN-12899 Standards [1]. The minimum required limits of the retroreflection coefficient for each color type have been considered and are stated as follows [1,2]:

- White color: R'=180 cd/lux/m^2
- Red color: R' = 25 cd/lux/m^2
- Blue color: R' = 14 cd/lux/m^2
- Yellow color: R' = 120 cd/lux/m^2

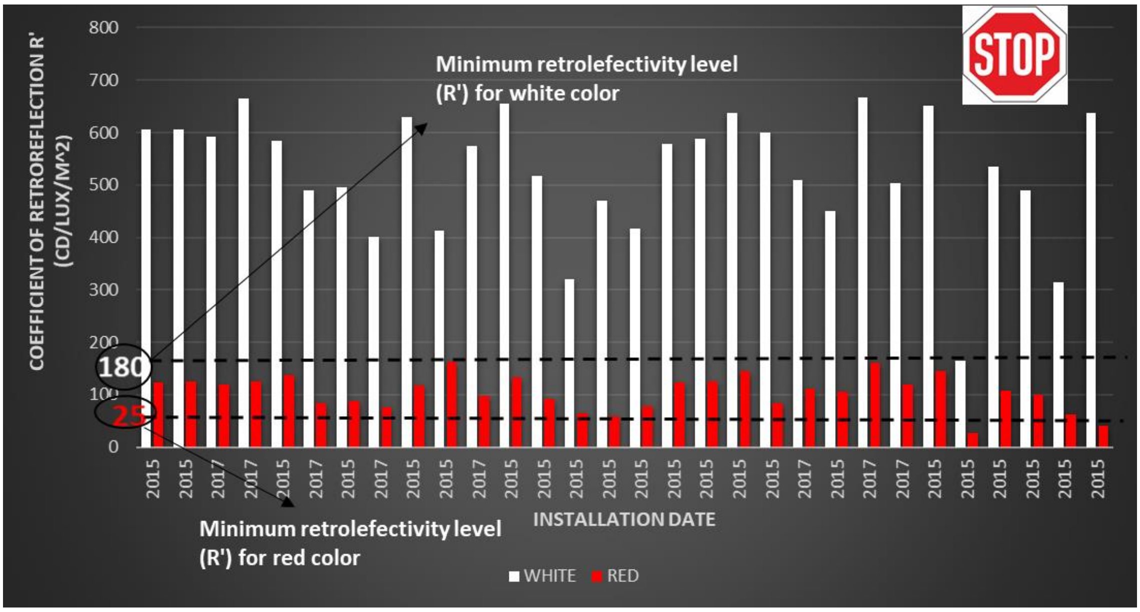

Figure 2: Coefficient of retroreflection versus Installation Date for white - red sign.

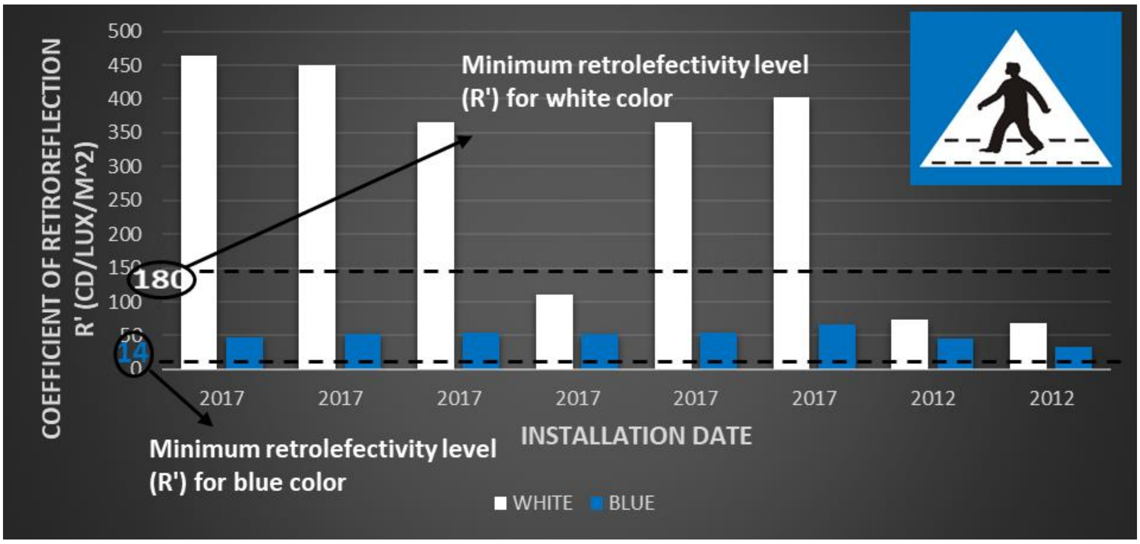

Figure 3: Coefficient of retroreflection versus Installation Date for white - blue sign.

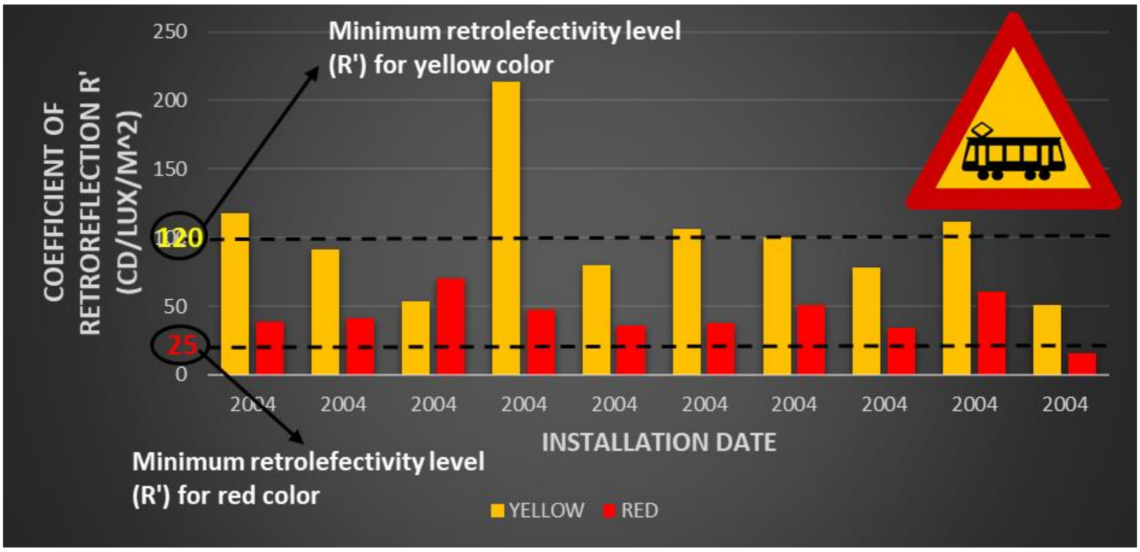

Figure 4: Coefficient of retroreflection versus Installation Date for yellow - red sign.

The representation of the relation between the coefficient of retroreflection (R') and the installation year was made through the construction of boxplots, regarding signs of white, red and blue colour. The measurement accuracy regarding signs made of yellow colour was not adequate, so they were excluded from the graphic representation.

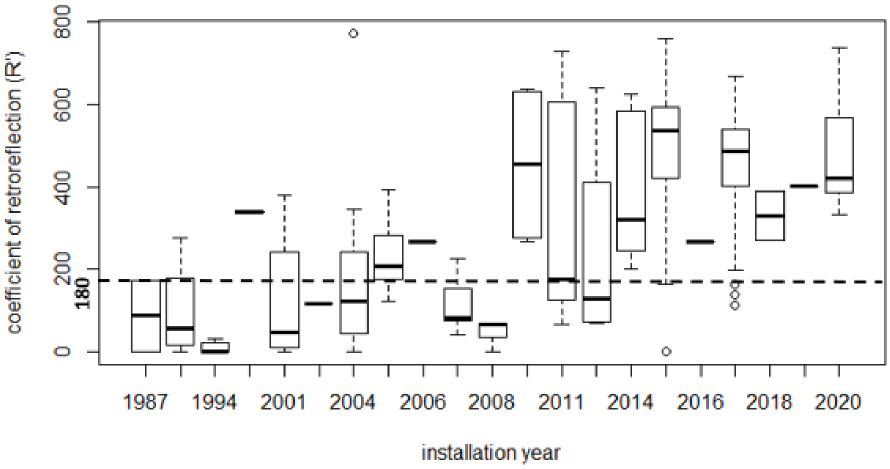

Figure 5: Coefficient of retroreflection versus Installation year for white color.

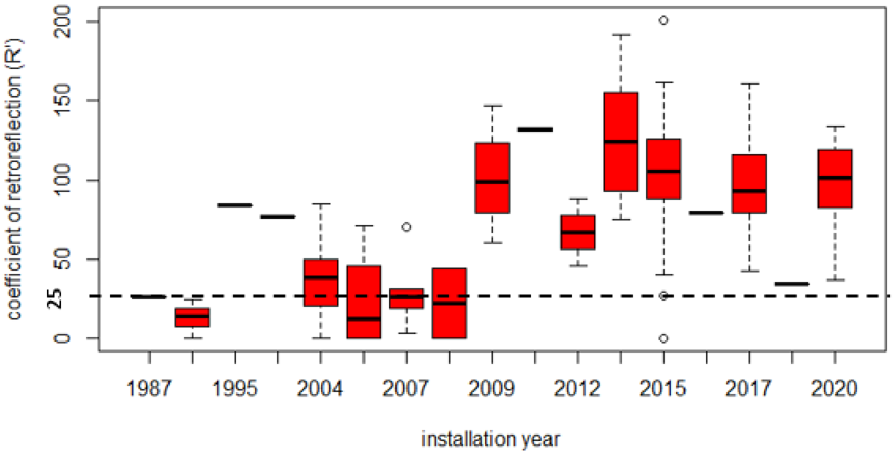

Figure 6: Coefficient of retroreflection versus Installation year for red color.

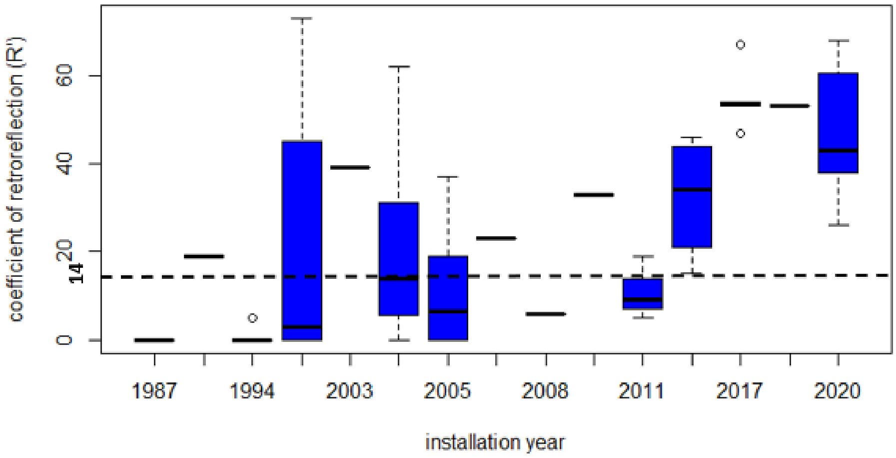

Figure 7: Coefficient of Retroreflection versus Installation year for blue color.

By interpreting the boxplots that are presented above it should be noted, that reflection issues are intense for the three different colours when the age of signs exceeds the lifetime of ten years.

4. Methods – Results

The linear regression modelling approach was found efficient, utilizing the R-studio software [4,5]. The parameters that were inserted in the models were the age (current year – installation year), the orientation expressed in degrees and total reflectivity.
The total reflectivity was expressed based on the percentage of the occupied colour area on each sign as it is stated in the following equation.

*Total retroreflection = (percentage of colour 1 area) * (value of retroreflection coefficient for colour 1) + (percentage of colour 2 area) * (value of retroreflection coefficient for colour 2)* (1)

where,
Colour 1 και Colour 2, express the two colours that each road sign contains (white, red , blue)
Retroreflection coefficient value (cd/lux/m2): the average value taken from field measurements

Figure 8 illustrates a typical example of the assumptions of colour area percentages.

	Warning Road sign with vehicles no entry permission: The red colour occupies the 80% of the sign area, whereas the white colour occupies the 20% of the sign area

Figure 8: Calculation Method for each color area.

During the analysis seven statistical models were developed in total. The first three models (Model 1, Model 2 and Model 3) were constructed by considering those sign types that have common colours (white-red, red-blue and white-blue). These first three models define as dependent variable the total reflectivity, whereas the independent variable was chosen to be the age of the signs as this it was identified to be the variable that heavily affected the behaviour of the models after having applied several iterations within R-Studio environment.

Moreover, Model 4, Model 5 and Model 6 were developed for each colour separately, i.e., white, blue and red. During the analysis of these models, the remaining reflectivity was set to be the dependent variable and in the same manner as the first three models (Model 1, Model 2 and Model 3), the age of the signs was selected as an independent variable. The remaining reflectivity was determined by subtracting the minimum required limits of retroreflection coefficient for each colour (180,14,25 repsectively) [1,2].

Regarding the last model (Model 7), total reflectivity (dependent variable) is predicted for the total number of the examined road signs (contains all colours and all types of signs). The main difference of Model 7 compared to the rest of the examined six models is that both age and orientation were considered as independent variables.

Below the equations given from the Linear Regression procedure as well as the model results can be seen.

4.1 Model 1: Prediction of total reflectivity for white and red colour sign.

Model 1 Equation: $\sqrt{Retroreflection} = 17.72 - 0.504 * (Age)$ (2)

Table 3: Parameter Estimates of the Linear Regression Model 1.

Parameter	B	Std. Error	t-value	p-value
Intercept	17.720	0.277	63.94	<0.001
Age	-0.504	0.030	-16.59	<0.001
df		1		
Adjusted R-squared		**0.6105**		

4.2 Model 2: Prediction of total reflectivity for red and blue color sign.

Model 2 Equation: $Retroreflection = 72.107 - 3.758 * (Age)$ (3)

Table 4: Parameter Estimates of the Linear Regression Model 2.

Parameter	B	Std. Error	t-value	p-value
Intercept	72.107	3.926	18.36	<0.001
Age	-3.758	0.359	-10.48	<0.001
df		1		
Adjusted R-squared		**0.7514**		

4.3 Model 3: Prediction of total reflectivity for white and blue color sign.

Model 3 Equation: $\sqrt{Retroreflection} = 12.03 - 0.360 * (Age)$ (4)

Table 5: Parameter Estimates of the Linear Regression Model 3.

Parameter	B	Std. Error	t-value	p-value
Intercept	12.030	0.831	14.48	<0.001
Age	-0.360	0.051	-7.09	<0.001
df		1		
Adjusted R-squared		**0.403**		

4.4 Model 4: Prediction of remaining reflectivity for white color sign.

Model 4 Equation: $$Retroreflection - 180 = 320.167 - 19.37 * (Age) \quad (5)$$

Table 6: Parameter Estimates of the Linear Regression Model 4.

Parameter	B	Std. Error	t-value	p-value
Intercept	500.167	5.652	88.50	<0.001
Age	-19.370	0.478	-40.55	<0.001
df		1		
Adjusted R-squared		**0.8629**		

4.5 Model 5: Prediction of remaining reflectivity for blue color sign.

Model 5 Equation: $$Retroreflection - 14 = 33.015 - 1.760 * (Age) \quad (6)$$

Table 7: Parameter Estimates of the Linear Regression Model 5.

Parameter	B	Std. Error	t-value	p-value
Intercept	47.015	1.469	32.01	<0.001
Age	-1.760	0.101	-17.52	<0.001
df		1		
Adjusted R-squared		**0.7537**		

4.6 Model 6: Prediction of remaining reflectivity for red color sign.

Model 6 Equation: $$\sqrt{Retroreflection} - 25 = 87.03 - 4.05 * (Age) \quad (7)$$

Table 8: Parameter Estimates of the Linear Regression Model 6.

Parameter	B	Std. Error	t-value	p-value
Intercept	112.030	2.068	54.17	<0.001
Age	-4.050	0.209	-19.36	<0.001
df		1		
Adjusted R-squared		**0.6242**		

4.7 Model 7: Prediction of total reflectivity of all the examined road sign – General Model

Model 7 Equation: $$Retroreflection = 225.981 - 9.805 * (Age) + 0.098 * (Orientation) \quad (8)$$

Table 9: Parameter Estimates of the Linear Regression Model 7.

Parameter	B	Std. Error	t-value	p-value
Intercept	225.981	6.808	33.20	<0.001
Age	-9.805	0.477	-20.56	<0.001
Orientation	0.098	0.035	2.67	0.008
df		2		
Adjusted R-squared		**0.6154**		

5. Conclusions

Retroreflection is a vital element, in order to assess the safety performance of road signs. An attempt was made through field measurements and statistical analysis to find the main causes of low retroreflection performance in traffic signs. The collected data showed, that the highest percentage of vertical signs installed in Poseidonos avenue do not achieve the retroreflection requirements in terms of quality as their lifetime exceeds ten years, thus it is recommended to be replaced immediately. Also, the signs of the investigated road segments of Poseidonos avenue appear to have reflectivity issues due to their exposure to solar radiation and therefore their lifetime is shorter compared to the other studied road sections even if their installation year is the same.

The majority of Information Signs appear to have the lowest values of reflectivity compared to the rest sign types due to the fact that they were installed later in relation to the rest examined signs. The examined Danger Warning Signs (yellow – red signs) do not exceed the minimum reflectivity limit of the yellow colour. The factors that contribute to this statement are the reflectivity requirements related to yellow colour, which appear to be higher compared to red colour according to the minimum values of retroreflection coefficient [1,2]. Regulatory STOP Type Signs located at minor roads of Poseidonos Avenue have very low levels of reflectivity. This fact affects driver's visibility and safety especially during night time, and possibly is a consequence of bad maintenance and old installation date.

The outcome of the modelling approach prove that the installation year of the signs and therefore their expected lifetime has higher importance compared to the sign orientation and is more essential from a statistical perspective. The sign orientation as well as their exposure to solar radiation constitute the basic factors that contribute to their reflectivity decrease. However, this statement requires further investigation in order to be adopted, as the quantitative and qualitative data are not adequate.

The model in which the total reflectivity of white and blue signs is predicted (Model 3) has lower adjusted coefficient R2 (0.41), compared to the rest of the models. By considering that the analysed type of signs in Model 3 consists of the smallest amount of observations, it can be said that further investigation is recommended, with the adoption of a larger dataset. On the other hand, the prediction model of total reflectivity (Model 7) can be considered as a general model and it is recommended to be implemented for all the different types and colours of road signs.

Last but not least, the general reflectivity prediction model, not only takes into consideration the importance of the orientation variable, but also contains the total number of measurements that were collected during the visual inspection. Therefore, it can be said that under certain circumstances and based on the collected data, Model 7 can be considered adequate to assess the variation of the examined variables.

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