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PREDICTING STATE OF TRAFFIC SIGNS USING LOGISTIC REGRESSION

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Abstract: Traffic signs as part of the overall traffic signalization system convey a message to road users using shapes, colours, text and symbols. They inform road users about regulations, warnings, directions, and guidance in traffic systems, in order to ensure safe traffic flow. In conditions of low visibility drivers receive less visual information in traffic which makes the perception of the surroundings, and thus the driving, significantly more difficult. In order to overcome the mentioned problems traffic signs must have satisfactory retroreflection properties and be properly positioned and maintained. Given the number of traffic signs on the roads, it is necessary to optimize their maintenance activities. The aim of this study is to develop a model for predicting the state of traffic signs regarding their retroreflective values based on their age. The study included 21,467 traffic signs on 30 state roads throughout the Republic of Croatia. Linear models for predicting state of signs were developed using binary logistic regression for each class of retroreflective material. Even though the models very accurately predict when the signs meet minimal prescribed retroreflection values for all the three classes of retroreflective material, they have certain downsides when predicting when the signs are not valid, i.e. do not meet minimal prescribed retroreflection values. Although the developed models did not show satisfactory accuracy, they represent unique prediction models of traffic signs functional service life, enabling prediction without conducting previous retroreflection measurements which, considering the number of in-service traffic signs, thus enables the optimization of the traffic signs maintenance system.

Keywords: traffic signs, retroreflection, logistic regression, road safety, traffic signs maintenance.

1. Introduction

Traffic signs are the basic elements of communication between the relevant road authorities and road users. With the use of colours, shapes and symbols they give important information with which they manage, regulate, inform and warn road users to ensure their safe movement throughout the transport network (Fleyeh and Roch, 2013). They should be easily recognizable and locatable within a complex visual scene; they need to clearly indicate the status of the message (legal, warning or information); convey the message efficiently, thereby minimizing visual distraction; be comprehensible so that drivers can recognize the action (or choice) to be taken and be located so that the driver has sufficient time to act on the message (Jamson et al., 2005).

As a basic means of communication between the road authorities and traffic participants, the improper installation and maintenance

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of road signs can significantly affect their perception, the quality of the transmitted message that they carry, thus affecting drivers' reaction time and general road safety.

For quality and safe traffic flow, all users must receive clear, readable, continuous and timely information in order to comply with them and adjust their behaviour, thereby avoiding non-desirable situations. Generally, three factors affect recognition of traffic signs: contrast, colour, and luminance. The most important factor, especially in regarding to safety is traffic signs luminance compared to the background luminance (Kipp and Fitch, 2009).

Sign luminance or retroreflection is determined by the coefficient of retroreflection R_A, which is defined as the coefficient of luminous intensity of a plane retroreflecting surface to its area. The metric unit for retroreflection coefficient is $cd/lx/m^2$ (Austin and Schultz, 2009).

Although over the past decades the industry has developed different types of retroreflective materials, the basic types of retroreflective materials involve enclosed glass beads, encapsulated glass beads, and prisms. The enclosed glass bead material uses small glass beads that are embedded into a layer of transparent plastic where the reflecting surface (a metallic shield) is placed behind the plastic. Encapsulated glass bead material uses glass beads placed on top of a metallic reflection shield and protected by transparent plastic sheet. The plastic sheet is supported slightly above the beads leaving space between the beads and the plastic. This space, which is filled with air, improves the retroreflectivity of the material. Prismatic material consists of small cube corners inserted into a transparent plastic film (Bischoff and Bullock, 2002).

In Europe these materials are classified into three groups: class I, II and III, of which class I and II use glass beads or prisms and class III only prisms.

Since traffic signs are primary means of communication it is of great importance that they convey the message to the driver at the right time in order to enable the driver to react in a timely manner. Under conditions of low visibility, which present very high risk conditions when it comes to traffic safety, timely transfer of the message depends, for the most part, on the retroreflection properties of the sign.

With respect to the above mentioned, it is necessary to properly maintain traffic signs and periodically test their retroreflectivity. Considering that the warranty period of the retroreflective materials given by producers is relatively long (class I - 7 years, class II and III - generally 10 years) it is necessary to optimize maintenance activities and traffic signs testing.

The aim of this paper is to develop a model for predicting the state of traffic signs using binary logistic regression, based on the retroreflection measurements and collected data. The state of traffic signs is defined as a categorical variable, using values 0 for *failure* and 1 for *pass*, which represents the fulfilment of the minimum prescribed retroreflection values. This means that a sign that meets the prescribed values is attributed with value 1 and if it does not meet the prescribed values, it is attributed with value 0.

The developed model enables prediction of the state of signs based on their age without previous retroreflection measuring. Predicting the state of signs is a precondition for defining and optimizing the traffic signs maintenance and replacement activities.

2. Literature Review

Considering the amount of traffic signs and their importance for traffic safety, scientific research activity focused on this issue is abundant. Generally, the mentioned scientific activity is divided into two directions. One trend is related to researching the drivers' levels of awareness of traffic sign (Macdonald and Hoffmann, 1991), their perception process, behaviour and reaction (Sun et al., 2011; Żakowska, 1995; Summala and Hietamäki, 1984) under different simulated or real driving conditions.

On the other hand, a number of authors have tried to predict the functional service life of traffic signs. Previous studies related to this issue are focused mostly on modelling of retroreflection degradation, or predicting the time when the traffic sign retroreflection will fall below the minimum prescribed level.

One of the first models was developed by Black et al. (1992), while they conducted a research that included 5,722 traffic signs. The research showed a correlation between the retroreflection and age of traffic sign, precipitation, elevation and temperature.

In 2001, authors Kirk et al. carried out a study in which they collected retroreflection data of signs older than 10 years. The obtained linear model showed insufficient relationship between the sign age and their retroreflection values, which is a result of the relatively small number of data (the research included 80 traffic signs) and insufficient range of sign age to obtain the full view of retroreflection degradation over time.

Research on a sample of 1,341 in-service signs was carried out by Bischoff and Bullock in 2002. The research showed that there is no significant correlation between the sign age and their retroreflection value, and the developed models have shown relatively poor accuracy given that the coefficient of determination R^2, depending on the colour and material, varies from 0.0152 to 0.3236.

A number of other authors such as Rasdorf et al. (2006), Kipp and Fitch (2009), Carlson et al. (2011), Pike and Carlson (2014) and Preston et al. (2014) have conducted similar studies with the purpose of describing the retroreflection degradation of traffic signs. These studies were performed with a satisfactory statistical sample and resulted in the development of mathematical models for predicting traffic signs retroreflection, however due to poor accuracy (R^2 has an average of 0.2) models are not applicable for optimization of the maintenance system and the replacement of traffic signs.

In addition to the above mentioned, the authors Brimley and Carlson (2013) highlighted several other limitations of previous studies, including the following: sign sheeting materials changing over time (new materials released, changes to current materials), age distribution of in-service signs, signs with poor retroreflectivity being replaced and thus not being included in degradation modelling, not accounting for initial retroreflectivity of signs, and sign age being the only consistent factor found to influence degradation.

Furthermore, previous studies include measurement of traffic signs retroreflection to determine the state of the signs. This research represents a different approach to the prediction of functional service life of the in-service traffic signs, in which the prediction is based only on the sign age.

3. Data Collection

The data used in this research was collected on state roads in the Republic of Croatia by the Department for Traffic Signalization at the Faculty of Transport and Traffic Sciences, University of Zagreb in 2015. Data is related to the retroreflection properties and sign age.

Traffic sign retroreflection coefficients were measured using a handheld retroreflectometer Zehntner ZRS 6060, the geometry of which corresponds to the values of the European Standard (EN 12899-1, 2008) which implies an observation angle (α) of 0.33^0 and an entrance angle ($\beta 1$) of 5^0. The entrance angle is primarily determined by the position of the sign on the side of the road and the geometry of an oncoming vehicle position and represents the angle that is formed between the light rays falling on the surface of the sign and the line that goes vertically from the surface. The observation angle is the angle between the incoming light ray and the reflected ray (EN 12899-1, 2008). Sign age is read from the label fixed on the back of the sign.

For the purpose of a statistical analysis of the collected data, in addition to the division per classes of the retroreflective material from which signs were made, traffic signs were also divided into two other groups, with respect to fulfilment and non-fulfilment of the minimum prescribed values of retroreflection according to the European regulations (EN 12899-1 for class I and II, and CUAP: Microprismatic retro-reflective sheetings for class III). According to the European legislation, the coefficient of retroreflection (R_A) of all printed colours, except white, shall not be less than 70% of the prescribed values. In case any of the colours on the sign do not meet the minimum prescribed value the sign must be replaced with a new one.

The study included a total of 21,467 traffic signs on 30 state roads throughout the Republic of Croatia. By measuring the retroreflection it was determined that 17,351 or 80.82% of traffic signs meet the minimum prescribed value of retroreflection, while 4,116 or 19.18% do not. Given that most of the signs in Croatia, according to legislation, must be made of a minimum class I materials, class I is the most common class in this study with a total of 13,255 or 61.75% traffic signs. Only certain traffic signs (stop signs, warning for pedestrians etc.) must be manufactured from class II and class III materials, which is why there is a smaller number of the mentioned signs: 6.580 or 30,65% class II and 1.632 or 7,60% class III (Table 1).

Table 1

Number of Signs According to the Class of Retroreflective Material, State of Signs and Road

State road	Section	Number of signs	Meet the prescribed value		Number of signs		
			Yes	No	Class I	Class II	Class III
3	Karlovac - Zdihovo	582	495	87	331	212	39
5	GP Terezino Polje - Lončarica	435	292	143	321	103	11
6	Vojišnica - GP Dvor	1.230	908	322	926	139	165
7	Vrpolje - GP Slavonski Šamac	419	316	103	289	124	6
23	Duga Resa - Kapela	857	715	142	449	243	165
30	Ogulinec - GP Hrv. Kostajnica	990	793	197	651	248	91
34	Slatina - Čađavički Lug	338	329	9	196	132	10
51	Gradište - Banićevac	743	644	99	502	214	27
53	Dilj - GP Slavonski Brod	495	367	128	357	120	18
55	Borovo - GP Županja	812	618	194	529	265	18
56	Drniš - Crivac	228	205	23	173	32	23
62	Veliki Prolog - Metković	400	320	80	219	113	68
69	Slatina - Novo Zvečevo	859	785	74	367	190	302
212	D7 - GP Batina	546	520	26	315	202	29
224	Mošćenica - Panjani	558	360	198	372	135	51
228	Jurovski Brod - Karlovac	508	406	102	276	176	56
306	Vir - Zadar	745	621	124	346	393	6
515	Našice - Đakovo	656	620	36	363	258	35
518	Ada - Jarmina	364	323	41	199	136	29
519	Borovo selo - Borovo	223	195	28	111	112	0
48	čvor Umag - GP Kaštel	586	440	146	472	114	0
303	Rovinj - čvor Kanfanar	410	357	53	269	132	9
32	GP Prezid - Delnice	454	371	83	355	97	2
62	Šestanovac - Veliki Prolog	839	560	279	565	238	36
53	GP Donji Miholjac - Krndija	1.030	933	97	543	437	50
34	Čađavički Lug - Josipovac	964	628	336	609	336	19
23	Kapela - Senj	697	519	178	460	92	145
38	Pakrac - Paka	2.340	1.907	433	1.370	883	87
37	Sisak - Glina	1.025	821	204	657	316	52
35	Gojanec - Očura	1.134	983	151	663	388	83
Total		**21.467**	**17.351**	**4.116**	**13.255**	**6.580**	**1.632**

4. Prediction Model for State of Traffic Signs

The statistical program SPSS was used to create a prediction model for state of traffic signs based on their age. Since the dependent variable (the state of the sign) is set as a categorical variable with values 0 for a sign that is invalid and 1 for a sign that is valid, binary logistics regression was used for modelling. Logistics regression is a specialized form of regression designed to predict and explain the binary (two-group) categorical variable rather than metric dependent measures. The independent variable in this case is the sign age, and it is set as a scalar quantity (continuous).

The first step of logistics regression is an analysis without the involvement of any independent variable in the model. The results of this analysis present a baseline for comparing the model with the final model involving a predictor (sign age) variable in the model. Table 2 shows the results of the initial analysis without the involvement of independent variable in the model. In the initial model, the software predicted that all of the traffic signs will be valid and the overall accuracy of the initial model for class I is 78.5%, for class II 85.0% and for class III 83.0%.

Table 2
Results of the Initial Model without the Involvement of Independent Variables for Each Class of the Retroreflective Material

				Predicted		
				State		
Class of retroreflection		Observed		Failure	Pass	Percentage Correct
Class I	Step 0	State	Failure	0	2.855	0,0
			Pass	0	10.400	100,0
		Overall Percentage				78,5
Class II	Step 0	State	Failure	0	984	0,0
			Pass	0	5596	100,0
		Overall Percentage				85,0
Class III	Step 0	State	Failure	0	277	0,0
			Pass	0	1.355	100,0
		Overall Percentage				83,0

After obtaining the initial model, the analysis has been carried out again, but this time including the independent variable. As previously mentioned, each type of retroreflective material was analysed separately and Table 3 shows linear equations for prediction of state of signs based on their age. In addition, the Table shows the contribution or importance of the predictor variable *Age* on the dependent variable *State* (column *Wald*). Since the Sig. is value lower than 0.005 with one degree of freedom (df), it can be concluded that the variable sign age contributes significantly to the predictive ability of the model. The column *Exp (B)* represents odds ratio (OR), i.e. the change in the odds of being in one of the categories of outcome when the value of a predictor increases by one unit (Tabachnick and Fidell, 2013). In other words, with the increase of sign age by one year the chance that the sign is valid is reduced by 6.92 times, i.e. the chance that the sign is invalid increases by 6.92 times.

Table 3
Final Model for Predicting the State of Traffic Signs Based on Their Age

Class of retroreflection	Equation	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
						Lower	Upper
Class I	y = 4,793 - 0,369xAge	2607,174	1	0,000	0,692	0,682	0,702
Class II	y = 3,431 - 0,233xAge	588,609	1	0,000	0,792	0,778	0,807
Class III	y = 4,241 - 0,379xAge	192,107	1	0,000	0,685	0,649	0,722

Omnibus tests of model coefficient shown in Table 4 indicate that the significant value (Sig.) for all the three classes of retroreflective material is lower than 0.005 which proves that the model which includes the sign age as independent variable is more accurate than the initial model. Chi-squared values for class I amount to 4,882.27, for class II 678.55 and 293.75 for class III with one degree of freedom.

Table 4
Omnibus Tests of Model Coefficients

Class of retroreflection			Chi-square	df	Sig.
Class I	Step 1	Step	4.882,270	1	,000
		Block	4.882,270	1	,000
		Model	4.882,270	1	,000
Class II	Step 1	Step	678,555	1	,000
		Block	678,555	1	,000
		Model	678,555	1	,000
Class III	Step 1	Step	293,750	1	,000
		Block	293,750	1	,000
		Model	293,750	1	,000

Considering that Omnibus tests of model coefficients are not reliable enough, the Hosmer and Lemeshowog goodness of fit test was also conducted. The Hosmer and Lemeshow test shows poor fit of the model (the Sig. value is 0.000 which is less than 0.005).

By analysing the accuracy of the model shown in Table 5 it can be concluded that the model has satisfactory overall accuracy for each class: class I 84.3%, class II 84.8% and class III 83.3%. However, a closer analysis reveals that although models predict very accurately when the sign will be valid for all three classes of retroreflective material (in 96.8% cases for class I, 99.5% for class II and 100% for class III) they have shortcomings in predicting when the sign will be invalid (in 38.4% cases for class I, 1.1% for class II and 1.4% for class III).

Table 5
Results of Classification

Class of retroreflection		Observed		Predicted		
				State		Percentage Correct
				Failure	Pass	
Class I	Step 1	State	Failure	1.097	1.758	38,4
			Pass	329	10.071	96,8
		Overall Percentage				84,3
Class II	Step 1	State	Failure	11	973	1,1
			Pass	30	5.566	99,5
		Overall Percentage				84,8
Class III	Step 1	State	Failure	4	273	1,4
			Pass	0	1.355	100,0
		Overall Percentage				83,3

The above findings were confirmed by Cox & Snell and Nagelkerke R square tests according to which the accuracy of the model for Class I is 0.308 (Cox & Snell) and 0.476 (Nagelkerke), 0.098 and 0.172 for Class II, and 0.165 and 0.276 for Class III, from which it can be concluded that on average between 19% and 30% of the dependent variable variability (State) can be explained by sign age.

According to the research results, it can be concluded that the state of the sign cannot be sufficiently accurately determined solely on the basis of sign age. In other words, degradation of retroreflection, and thus the state of the sign or their functional service life is affected by other factors, such as environmental conditions including sunlight, temperature, dust and moisture, as well as sign direction and position.

5. Conclusion

Predicting the functional service life of traffic signs is a key part of developing a comprehensive sign maintenance program, which was the reason for conducting this study, whose objective was to develop a prediction model for state of the in-service traffic signs based on their age.

Previous studies were directed at describing the degradation of traffic signs retroreflection, thus defining their state of validity and functional service life. The stated studies conducted to determine the state of the signs include measuring of traffic signs retroreflection and they have a number of other restrictions. In order to avoid the disadvantages and limitations of previous studies, a model for predicting the state of the traffic signs based on their age was developed. The basis for modelling was a database of traffic signs on 30 state roads throughout Croatia. The study included 21,467 traffic signs and resulted in linear models predicting the state of traffic signs based on their age for each class of retroreflective material. Statistical analysis showed that the age of traffic signs contributes significantly to the predictive ability of the model. By conducting Hosmer and Lemeshowog goodness of fit test it was concluded that the model provides a poor fit. Also, although providing very accurate predictions for all the three classes of retroreflective material of when the sign will be valid (in 96.8% of cases for class I, 99.5% for class II and 100% for class III), the models have downsides when predicting when the sign will be invalid (in 38.4% of cases for class I, 1.1% for class II, and 1.4% for class III), from which it can be concluded that the functional service life of the sign cannot be sufficiently accurately determined based only on sign age.

Even though the developed models have not shown satisfactory accuracy, they are still unique models and represent the basis for further research and development of new and more precise models which will include the impact of a number of other factors such as environmental conditions including sunlight, temperature, dust and moisture, as well as sign direction and position, all with the purpose of optimizing the traffic signs maintenance system.

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