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17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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PREDICTING TRAFFIC SIGNS FUNCTIONAL SERVICE LIFE USING SURVIVAL ANALYSIS METHOD

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Abstract

In order to fulfil their function, traffic signs must be visible to all traffic participants in all weather and traffic conditions. This is especially important in conditions of reduced visibility in which, due to the limited amount of visual information, signs present basic elements for informing traffic participants about the upcoming road condition. The quality and timeliness of the informations transfer, in mentioned conditions, are directly related to the retroreflective characteristics of traffic signs. If the signs do not meet the minimum prescribed values of the retroreflection, the authorities should replace them. Given the amount of traffic signs on the roads, the type of retroreflective material and their age, the substitution of signs that do not meet the prescribed values requires significant financial resources. The purpose of this paper is to predict, using Survival analysis method, when the traffic signs, from the aspect of retroreflection, become dysfunctional, i.e. when their replacement is required. The results of this paper may help the road authorities in planning periodic measurements of traffic signs retroreflection and ultimately optimizing the traffic signs maintenance activities, all with the goal of increasing the overall road safety.

Keywords: traffic signs, traffic safety, survival analysis, retroreflection, asset management

1 Introduction

Traffic signs use shapes, colours, text and symbols to convey a message related to the regulations, warnings, directions and general information to the road users and as such present a basic means of communication between road authorities and users.

Although their importance for overall safety is unquestioned, research shows that the driver's awareness of traffic signs differs between 10 % and 40 % [1,2,3]. One of the reasons for this, according to [4, 5], lies in the fact that drivers, with the increase in familiarity of the driving route, are less attentive to traffic signs and more susceptible to incidental stimuli, meaning that there is a possibility of overlooking significant changes in road signage. In other words, on known roads drivers rely on the experience and "memory" and they automate their driving process, while on the unknown roads they are scanning the environment more actively in order to find enough information needed for a safe ride. Also, the perception of the signs will be affected by driver's expectation and the purpose of journey, especially those experienced, who in some ways enter a state in which they have no active attention for the driving task and perform on 'autopilot' [6].

In order to perform their function and for drivers to be able to perceive them timely, traffic signs must be designed in accordance with ergonomic principles, meaning that they should be comprehensible so that drivers can recognize the action (or choice). They should also clearly indicate the status of the message (legal, warning or information) and be properly located in the road environment [7].

Furthermore, they should have satisfying retroreflective properties to ensure their conspicuousness in the conditions of reduced visibility. When driving in conditions of reduced visibility, drivers receive significantly less visual information which makes the perception of the environment, and thus the driving, considerably more challenging [8]. To achieve their visibility in mentioned conditions, traffic signs are made from retroreflective materials which gives them the ability to reflect light from the vehicle headlights back to the driver, giving the sign an illuminated appearance [9]. During the exploitation, the retroreflection of signs, under the influence of many factors, is reducing. To ensure minimum prescribed retroreflection values, signs should be periodically tested. Given the number of traffic signs on the roads, it is necessary to optimize their maintenance activities.

For this purpose, a series of [8, 10-18] models have been developed in order to predict functional service life of traffic signs. The aim of the mentioned studies was to develop mathematical models based on relevant factors, such as the age of the sign, position, height and sign orientation, precipitation, elevation etc. to determine the moment in which the retroreflection of signs will not meet the minimum prescribed values, i.e. when signs needs to be replaced. The aim of this paper is to determine the duration of signs made from the different retroreflective materials, based on the traffic signs database from the state roads in Croatia, using the Survival analysis method.

2 Research methodology

For the purposes of conducting research and determining the time interval in which a particular material will meet the minimum prescribed retroreflection values, the database of traffic signs on the state roads across the Republic of Croatia was used. Although there were significantly more traffic signs on the observed road network, to obtain the equal number of each retroreflective material, the study comprises of 31 017 signs, or 10 333 signs per each retroreflective material. Considering the type of retroreflection, the 8 436 signs made of class I material are spherical, while 1 903 are with the prismatic retroreflection. Out of a total of 10 339 signs made of class II, a total of 5 265 are spherical and 5 074 are prismatic. The signs made of class III are exclusively made with prismatic reflection and as such have the best retroreflective properties. As mentioned above, they include a total of 10 339 signs. The average age of class I signs is 9.60 years, class II 8.19 and 6.78 years for class III. Figure 1 shows the percentage distribution of individual classes of retroreflecting materials.

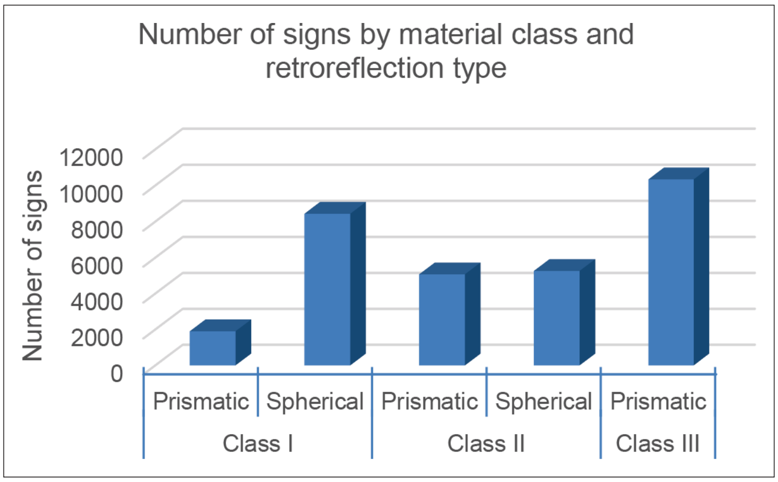

Figure 1 Number of signs by material class and retroreflection type

During data collection, on each sign the retroreflection coefficient (RA) of each colour except black which does not reflect but absorbs light, was measured according to the methodology described in [8], which implies the use of handheld retroreflectometers. The geometry of used instrument (Zehntner ZRS 6060) corresponds to the values of the European Standard [19] which implies an observation angle (α) of 0.33º and an angle of entry (β1) of 5º. Observing and entrance angle are shown in Figure 2.

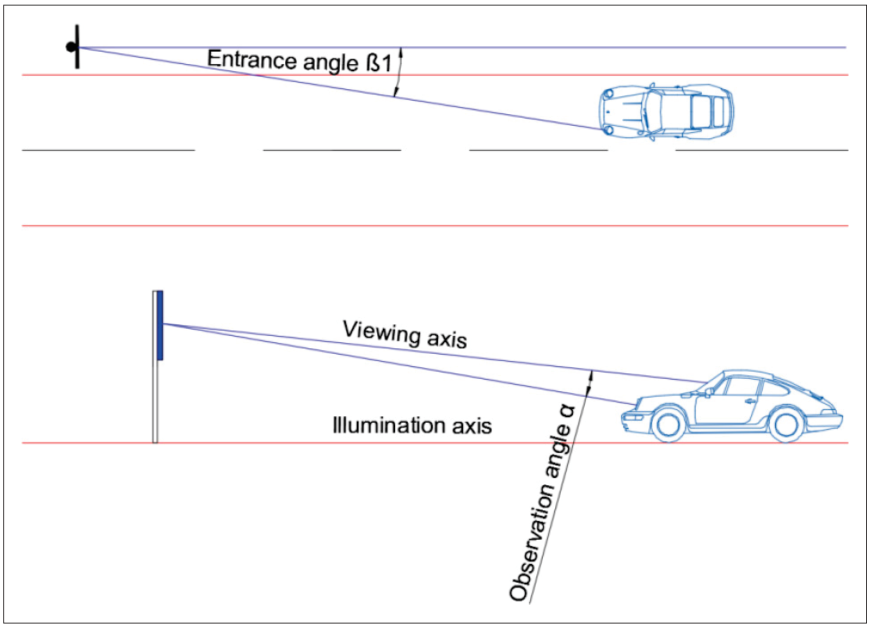

Figure 2 Entrance and observation angles for a traffic sign (Source: [8])

Before measurement, each sign was cleaned to ensure the relevance of the measurement, since an impure sign may reduce measured values up to 33 % [20]. In addition to the retro-reflection coefficient, other relevant data were collected such as: the date of production, implementation date, the class and the type of retroreflective material.
As mentioned before, to determine the duration of a particular retroreflective material, a Survival analysis method was used. The method represents a collection of statistical procedures for data analysis, for which the outcome variable of interest is time until an event occurs or in other words it is the study of time between entry into observation and a subsequent event [21]. Today, the method is used in different fields, but mostly in medicine for studying death, disease, relapse or recovery [22]. In order to determine the time when the retroreflection values of each sign and retroreflection material falls below prescribed, the retroreflection values of the measured signs are compared to the minimum and hence defined as satisfactory or unsatisfactory. In accordance with the European regulations [19, 24], the minimum coefficient of retroreflection RA of traffic signs must match the values shown in Table 1. The coefficient of retroreflection of all printed colours, except white, should not be less than 70 % of the values shown in Table 1.

Table 1 Retroreflection coefficient RA

Geometry		Minimal RA values by colour (cd/lx/m²)			
α	β_1 (β_2 = 0)	White	Yellow	Red	Blue
Class I					
0.33°	+5°	50	35	10	2
Class II					
0.33°	+5°	180	120	25	14
Class III					
0.33°	+5°	425	275	85	28
Source: [19, 24]					

3 Results

As outlined in the previous chapter, the main criterion for technical validity of the sign, in this study, is its compliance with the minimum prescribed retroreflection values shown in Table 1. Measuring the retroreflection coefficient it was determined that a total of 18.22 % of the analysed signs do not meet the values as shown in Figure 3. Since signs made of class I material have the worst retroreflective properties it is logical that the technical incorrect signs mostly belong to this class (a total of 1 845 or 17.84 % of the total number of class I signs). Than follow signs made of class II material, from which a 1 441 or 13.93 % from the total number of class II signs do not meet the minimum required conditions. From the class III signs, 2 364 (22.86 %) signs are not technically correct. The total age of signs which do not meet the minimum prescribed values is 10.45 years, which is generally more than the warranty period for all three classes of materials. On the other hand, the average age of signs that are technically correct or meet the prescribed retroreflection values is 5.94 years.

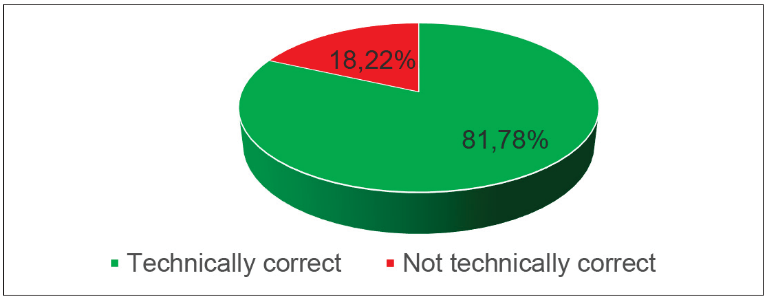

Figure 3 Percentage share of technically correct and not correct signs

As already mentioned, Kaplan-Meier survival analysis was used for conducting the analysis. The survival function is calculated using equation (1).

$$F_x(t) = \frac{F(x+t) - F(x)}{S(x)} \tag{1}$$

Where variable x is the time when the retroreflection values of each sign and retroreflection materials falls below prescribed (variable x+t); S(x) represents the survival function or opposite event to F(t).

Each subject is characterized by three variables: 1) their serial time ($t_1 < t_2 < t_3 < ... < t_{k+1}$), 2) their status at the end of their serial time (event occurring or censored) (d_j), and 3) the study group they are in (c_j) [23], [25]. In this case, the serial time is defined as the age of the sign, the technical correctness is their status and the study group is the class of retroreflective material. The status of interest is the technical incorrectness which can have two results: a subject can have the event of interest or they are censored. If we assume that variable T is discrete, then the probability 1-F(t) is defined:

$$1 - F(t) = \prod_{t_j \le t} (1 - \lambda_j) \tag{2}$$

$$\lambda_j = P\left[T = t_j T \ge t_j\right] \tag{3}$$

Maximal likelihood of event, in this case failure of the sign, is calculated based on following equations:

$$\hat{F}(t) = 1 - \prod_{t_j \le t} (1 - \hat{\lambda}_j) \tag{4}$$

$$\hat{\lambda}_j = \frac{d_j}{n_j} \quad (5)$$

From the results presented in the Table 2, it can be concluded that the median estimation age in which the signs are no longer technically correct is 15 years; 15.0 for class I, 14.0 for class II and 11 for class III. The 95 % confidence interval for class I is between 14.703 and 15.297, for class II between 13.797 and 14.203 and for class III between 10.875 and 11.125 years.

Table 2 Survival analysis results

Class	Median			
	Estimate	Std. Error	95 % Confidence Interval	
			Lower Bound	Upper Bound
Class I	15.000	0.151	14.703	15.297
Class II	14.000	0.104	13.797	14.203
Class III	11.000	0.064	10.875	11.125
Overall	13.000	0.062	12.878	13.122

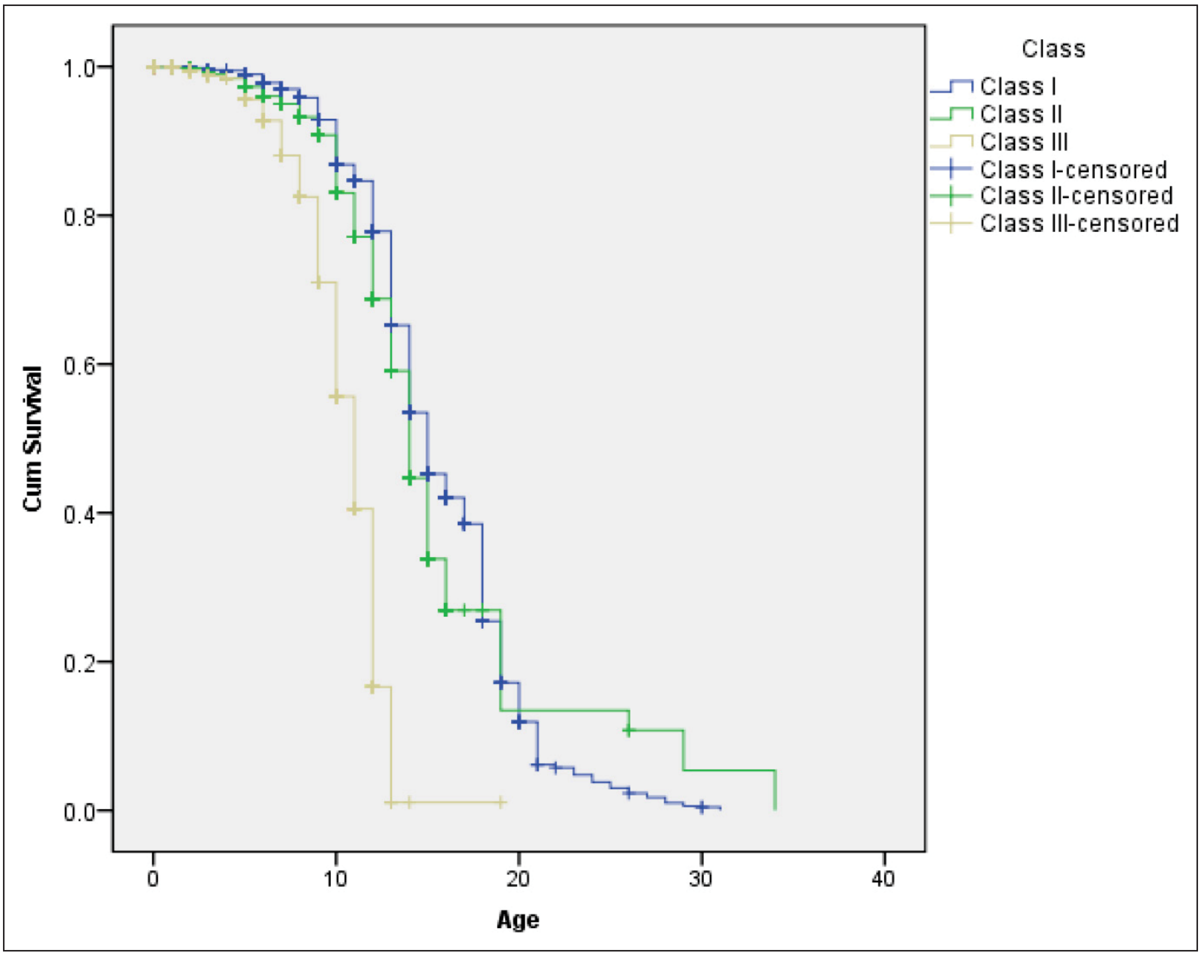

Figure 4 Survival curve of analysed materials

Based on the survival curve, shown in Figure 4, it is evident that the life expectancy of each retroreflective material is significantly different but most of the signs (› 50 %) of all three classes meet the minimum prescribed retroreflection values for more than 10 years. Although materials made of class III have the best retroreflective properties and have the longest manufacturer's warranty period (between 10 and 12 years), survival analysis shows that their life span is the shortest. The reason for this lies in the fact that, according to Croatian regulations, only a few signs must be produced with class III retroreflecting material. These are mostly signs of great importance to the road safety, such as fluorescent yellow-green chevrons and markers for marking the side reduction of road profiles. Due to their function, the mentioned signs are placed at lower heights, on average between 50 and 90 cm, which is why they are more exposed to the impact of stones and other dirt, which ultimately speeds up their degradation. A similar situation is with class II materials from which mostly white-red chevrons, also set at lower heights, are made. Unlike classes II and III, the average height of class I signs is 160 cm, which is why they are less exposed to mentioned effects and ultimately their lifespan, according to the performed analysis, is the longest.

4 Conclusion

Traffic signs represent elements of a traffic control plan which give the driver's necessary information's needed for a safe ride. As they use shapes, colours, text and symbols to convey their message, their visibility is of key importance for timely perception of their meaning and message. This is particularly important in low visibility conditions when the amount of visual information in the environment is reduced, the driver's visual field is narrowed, and the sharpness of his vision as well as his ability to distinguish the colours is diminished.

For these reasons it is necessary to ensure an adequate quality of the traffic signs, which largely relates to the level of night-time visibility, i. e. coefficient of retroreflection. As the quality of traffic signs degrades during their exploitation, it is necessary to conduct periodic retroreflection measurements to ensure that the minimum prescribed values are met. Given the number of traffic signs on the road, it is essential to optimize their maintenance activities. The purpose of this paper is to determine the duration of traffic signs from various retroreflective materials using Survival analysis method. The research results show that all three classes of material have a lifetime of 13 years, i.e. between 12.878 and 13.122 years. Ultimately, estimated duration for signs made of class I is 15 years, class II 14, and class III 11 years. Although classes II and III have a significantly higher initial coefficient of retroreflection and longer warranty period, due to the fact that in Croatia only specific signs, implemented at relatively low heights, are made from mentioned materials, their lifespan, according to the conducted analysis, is somewhat shorter compared to class I, which represents the material with lowest retroreflection properties. However, if the aspect of maintenance is considered, it can be concluded that most (> 50 %) of the signs, regardless of the material class, meet the minimum prescribed values of retroreflection for more than ten years. Ultimately, this means that the retroreflection of traffic signs, as their most important quality characteristic, should be tested after their implementation, in order to determine the initial sign's quality, and between 10 and 15 years after the implementation. Based on these results, relevant road authorities may plan activities and financial resources needed to maintain the desired traffic quality.

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