Agronomy Research **18**(S1), 888–903, 2020
https://doi.org/10.15159/AR.20.062

Recognition of retroreflective traffic signs by a vehicle camera system

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Abstract. The systems of traffic sign recognition are based on the evaluation of three components of every sign: shape, colour and pictogram. There are different factors that can have an influence on the efficiency of detection and recognition of these components. One of the most important factors is the quality of the retroreflective sign surface. Retroreflective sheeting improves the readability of colour and pictogram of traffic sign by increasing brightness of its background and/or legend elements. The aim of the paper is to provide a comprehensive survey of the efficiency of sign's recognition by a modern vehicle camera system. The traffic sign sheeting was measured by the handled retroreflectometer. Then this measurement was repeated by the modern camera system used for recognition of traffic signs in the vehicle. The results of this paper present the analysis of the recognition efficiency of traffic signs and the overview of other factors that can have a significant impact on sign detection and recognition distance. The results can be used for creation a traffic sign database for learning-based recognition techniques to vehicle camera systems.

Key words: ADTF, recognition distance, attributes of the sign, TSDR.

List of abbreviations:

ADTF	The Automotive Data and Time triggered Framework	*d*	Cohen's d
ANOVA	Analysis of variance	*df*	Degree of freedom
C	Internal retroreflective contrast	*N*	Number of samples
R_A	Coefficient of retroreflection	R^2	Coefficient of determination
RD	Recognition distance	*SD*	Standard deviation
TAS	Travel Assist System	μ	Mean
TSDR	Traffic sign detection and recognition	η_p^2	Eta squared partial

INTRODUCTION

Background and the importance of the study

A fully autonomous vehicle requires determining exact position of the car throughout the whole trip. The GPS navigation system allows car to define its position in the tree-dimension system relative to other road users and elements of infrastructure.

However, it has two main drawbacks – the inaccuracy of determining the location (European GNSS Agency, 2020) and the use of off-line maps. Therefore, any temporary change (such as repair works on the road) is not considered by this system.

TSDR system is one of TAS that allows increasing the safety of driving by using the vehicle camera system in conjunction with navigation systems. Heavy traffic and a large number of signs increase the likelihood that the driver may not notice some important sign. TSDR eliminates this issue by showing important traffic information on the panel desk in the car and it can provide sound signal warning.

Nevertheless, TSDR system has its own limitation based on difficulties of sings recognition. The main problems of identification of traffic sings can be divided into three main groups: outdoor condition (i.e. weather and lighting conditions, presence of obstacles in front of the sign, scene complexity), vehicle camera system (i.e. quality of video source, vibration by a moving vehicle), properties of traffic sign (i.e. location of the sign, damage of sign surface, size, shape and colour) (Ritter et al., 1995; Paclík et al., 2000; Hsu & Huang, 2001; de la Escalera et al., 2003; Fang et al., 2004; Toth, 2012; Wali, 2015).

In terms of research, there is a growing interest in developing efficient and reliable TSDR system (Wali et al., 2019) that allows to increase the accuracy of detection and recognition sign by developing new algorithms and methods to minimize the effect of factors influencing on traffic signs. However, it is worth mentioning, that many researchers tested their algorithms using existing traffic sign databases (i.e German TSDR Benchmark (Zaklouta & Stanciulescu, 2014; Yin et al., 2015; Zhu et al., 2016; Lim et al., 2017; Khan et al., 2018), Sweden Traffic Signs Dataset (Yin et al., 2015), Chinese Traffic Sign Detection Benchmark (Zhu et al., 2016) Korean Traffic Sign Dataset (Lim et al., 2017; Khan et al., 2018 etc.). These databases of traffic signs scene and images representing them is an essential requirement for improving the TSDR system (Wali, 2015; Wali et al., 2019) because it is used for self-adaptive systems that 'are able to adapt their behavior at runtime without human intervention' (Dajsuren & van den Brand, 2019). Nevertheless, the use of such database in research has one significant drawback - they become obsolete. New technologies allow creating pictures of road scenes in better quality and with better expansion than for example in 2013, when the German TSDR Benchmark was created (German Traffic Sign Benchmarks, 2013) . In addition, regulations of use of traffic signs were changed. For example, in the Czech Republic during 2015–2016 (The Decree No 294/2015 Coll., 2015, The Decree No 84/2016 Coll., 2016), 15 new signs' classes were introduced, so a large number of new traffic signs have been installed.

Accordingly, the authors are convinced that the precise knowledge of the sign's properties and their technical standards and requirements is more useful for training TSDR systems then a prepared large database (Ministry of Transport of the Czech Republic, 2017). Using programmes that simulate traffic signs under various conditions for training TSDR system may become a more effective tool for a future. Moreover, the self-adaptive system needs a huge number of images of real traffic scenes (signing) under various light and weather conditions for teaching of this system. This is a big disadvantage because creating database like this (real road or traffic) scenes is resource intensive.

In a large number of studies the evaluation of the accuracy of the new methods or algorithms was based on determining the percentage of correctly defined signs to the total number of signs (Vitabile et al., 2001; Fatmehsari et al., 2010; Hechri & Mtibaa, 2012; Laguna et al., 2014; Islam & Raj, 2017; Zhu et al., 2017; Khan et al., 2018). And only a few researchers for an assessment TSDR system used also the recognition speed (Yin et al., 2015), average time needed for recognition (Zaklouta & Stanciulescu, 2014; Gomes et al., 2017). Gao et al. (2006) simulated traffic signs on different distances for testing their method for recognition traffic signs. In this study, the author proposes to use the recognition distance (hereinafter 'RD') as a measure of evaluating the effectiveness and performance of the TSDR system. RD – is the distance in which the TSDR system correctly recognises the traffic sign. The longer the distance, the more time has the driver to react, the safer driving. This parameter becomes useful in evaluating the recognition efficiency of warning signs, for which it is especially important to warn the driver as soon as possible of potential danger, obstacle or hazardous conditions.

Attributes of a traffic sign – a glossary of terms

The main attributes of traffic signs that are discussed and examined in the study are presented in Fig. 1. Traffic signs consist of two basic components:

1. Sign panel (or sign surface) – 'a separate panel or piece of material containing a word, symbol, and/or arrow legend that is affixed to the face of a sign' (MUTCD, 2012).
2. Sign post – a post bearing a sign.

The Czech Republic standards (e.g. ČSN EN 12899-1 (2007), TP 65 (2013)) prescribe specific limit values for the following attributes:

1. Position of the sign:
    - Lateral offset – is a distance from the edge of the shoulder of the road to the nearest edge of that sign (Traffic signs, 2008).
    - Vertical clearance – is the height from the lowest edge of the sign plate to the road surface (Traffic signs, 2008).
    - Siting – traffic signs are sited on the right-hand or left-hand sides of the road.

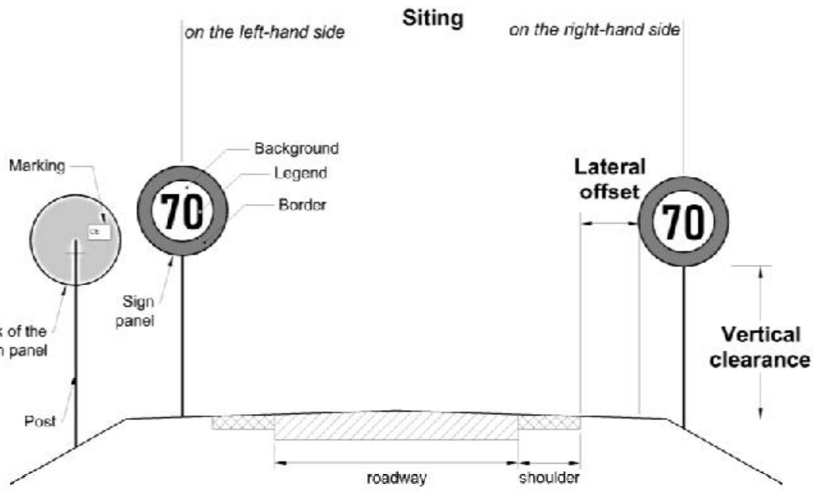

Figure 1. The main sign attributes that are discussed in the study. Source: Adopted from TP 65 (2013).

2. Elements of sign surface (MUTCD, 2012):
   - Legend – the message on the face of a sign panel (including text, arrows, route markers and special symbols) (Traffic signs, 2008).
   - Background – the element of the sign with the largest surface area of the sign.
   - Border – the element that is different in colour (material) from the background.
3. Properties of surface elements:
   - Coefficient of retroreflection (R_A) – is the ratio of light returned versus the light striking a define section of sign surface area (Ré et al., 2010b). The coefficient is expressed in candelas per lux per square meter (cd. $lx^{-1}.m^{-2}$).

The properties of surface elements that has been introduced by authors:

- Area of colour – the proportion of the area occupied by one colour to the total area of the sign, expressed as a percentage.
- Retroreflective contrast between background and border or retroreflective internal contrast (hereinafter 'Contrast') was derived using Michelson equation of luminance contrast (1) and definition of R_A (2).

$$C_M = \frac{L_{max} - L_{min}}{L_{max} + L_{min}} \quad (1)$$

where C_M – Michelson luminance contrast (-), L_{min} and L_{max} – the minimum and maximum luminance of two colours ($cd \cdot m^{-2}$).

$$R_A = R_L \cdot \cos\beta = \frac{L \cdot \cos\beta}{E} \quad (2)$$

where R_A – coefficient of retroreflection of one colour (cd.$lx^{-1}.m^{-2}$), R_L – coefficient of retroreflected luminance (cd.$lx^{-1}.m^{-2}$), β – is the entrance angle of the light incident on the road sign (°), L – luminance of one colour ($cd \cdot m^{-2}$), E – is the illuminance at the sign plate created by the light source, perpendicular to the direction of illumination (lx).

The retroreflective contrast equation (3) is obtained by substituting Eq. 3 into Eq. 2.

$$C = \frac{\frac{R_{A\,(B)} \cdot \cos\beta}{E} - \frac{R_{A\,(BO)} \cdot \cos\beta}{E}}{\frac{R_{A\,(B)} \cdot \cos\beta}{E} + \frac{R_{A\,(BO)} \cdot \cos\beta}{E}};$$

$$C = \frac{\frac{\cos\beta}{E}(R_{A\,(B)} - R_{A\,(BO)})}{\frac{\cos\beta}{E}(R_{A\,(B)} + R_{A\,(BO)})};$$

$$C = \frac{R_{A\,(B)} - R_{A\,(BO^1)}}{R_{A\,(B)} + R_{A\,(BO^1)}} \quad (3)$$

where C – internal retroreflective contrast (-); $R_{A(B)}$ – coefficient of retroreflection for background (cd. lx^{-1} m^{-2}); $R_{A(BO)}$ – coefficient of retroreflection for border (cd. lx^{-1} m^{-2}); β – is the entrance angle of the light incident on the road sign (°); E – is the illuminance at the sign plate created by the light source, perpendicular to the direction of illumination (lx); [1] – for the retroreflective sign with legend only R_A of legend is used.

Purpose of the Study

The main aim of the study is to assess effectiveness of TSDR and its ability to recognise traffic signs. The effectiveness is evaluated by new parameter suggested by authors - the measure of recognition influenced by of above-mention sign characteristics on distance in which the traffic sign was correctly recognised.

MATERIALS AND METHODS

The current study is divided into five parts: a selection of the study location, creation a database with the basic signs' characteristics, R_A measurement of traffic signs, video recording of selected traffic signs by the vehicle camera system and statistical analysis of data.

Study location

The retroreflective traffic signs alongside of roads in the Czech Republic were chosen for this study. The selected sections of the major arterials (*'silnice I. třídy'*) number I/11 and I/35 are represented in Fig. 2. These arterials were deliberately selected because of their recent reconstruction of pavement (the period from 2017 and 2019) which entailed replacement of vertical road traffic signs.

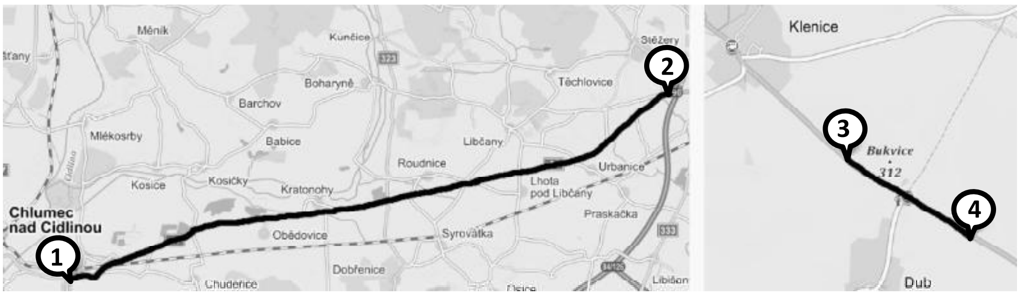

Figure 2. The representation of selected road sections of the Czech Republic. (Left) Section of the major arterials number I/11 from Nové Dvory, in the direction of Hradec Králové. (Right) Section of the major arterials number I/35 from Hradec Králové, in the direction of Klenice. Source: (Mapy.cz, 2020).

According to the Czech regulations (TP 65, 2013), the class of retroreflection for all signs should not lower than RA2. It is expected that more than 90% will correspond with TP 65 (2013). All general conditions and requirements of traffic signs' positioning and used materials are described the in part 'INTRODUCTION', subsection 'Attributes of a traffic signs'.

Creation of an information database

There is not a unified information system for traffic signs in the Czech Republic. A large number of suppliers of reflective films and signs' manufacturers make it impossible to collect information remotely. Consequently, information about each of the signs was collected manually on the site.

The Czech standard ČSN EN 12899-1 (2007) obliges manufacturers to affix a marking containing important information about the road sign on its backside (Fig. 1). This marking provides information about the date when the marking was affixed, visibility properties (class of retroreflective sheeting), durability, the resistance of weathering and etc. Nevertheless, this marking does not contain information about the type of used reflective film that may have a different level of retroreflection within the same class.

Under these circumstances, three photos were taken for each traffic sign: general photo (to determine the category of a sign), photo of marking and a photo of the structure of the reflective film (to determine the type of film). Based on these three photos, an information card was created for each sign, that also includes GPS coordinates, the orientation of the sign, lateral and vertical positioning, the area of colour (Fig. 3). In total 100 such cards were created (Table 1).

The number of all assessed retroreflective traffic signs is represented in Table 1. Traffic signs were divided according to their categories, technology and class of the retroreflective sheeting.

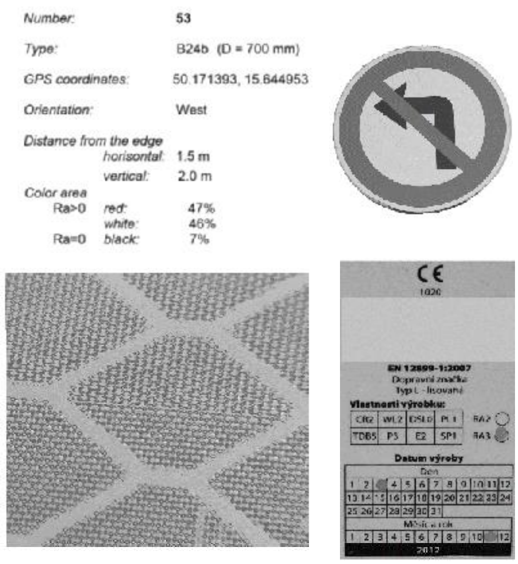

Figure 3. An example of an informational card from the created database of a traffic sign. Source: Autors' work.

Six main categories of traffic signs have been tested: mandatory; prohibitory; priority; direction, position, or indication signs; information, facilities, or service signs and additional panels (classification according to the Czech law (The Decree No 10/2019 Coll., 2015). The glass bead technology was provided by retroreflective class RA1, the microprismatic technology – by retroreflective classes RA2 and RA3 (Table 1). The classification depends on the mandated minimum R_A values which increase with the class number (ČSN EN 12899-1, 2007).

Table 1. Summary of surveyed retroreflective traffic signs according to their category and the class of sheeting

Technology[1]	Class[1]	Number of traffic sign					
		warning	priority	prohib.	inform.	direct.	addit.
Glass Bead	RA1	1	3	9	3	1	3
Microprismatic	RA2	5	11	37	2	3	7
	RA3		4	6			5
Total number of signs		100					

[1] – according to ČSN EN 12899-1 (2007).

As can be seen in Table 1, the majority of traffic signs (80 signs) have retroreflective properties with classes R_{A2} and R_{A3}, that means 80% of all signs correspond to the national standard TP 65 (2013) but it is less than it was expected.

Measurement of the R_A

The retroreflective level of traffic signs was measured by handled retroreflectometer Zehntner ZRS 6060. The retroreflectometer allows determining R_A in accordance with the Czech standard ČSN EN 12899-1 (2007), for illumination angle 5° and three observation angles – 0.2°, 0.33°, 2°.

The measuring principle with the retroreflectometer to get R_A value was the same for all measurements. The calibration of the device is necessary condition before the equipment use; then the retroreflectometer is planted on the surface of the traffic sign and the trigger is pulled. The measurement values of R_A are shown beside each observation on the display. Each measurement also contains information about the colour of the sample, ambient temperature, relative humidity and GPS coordinates. Using the retroreflectometer, three readings of each sign colour were collected.

The data analysis software 'MappingTools' was used to export data from the retroreflectometer and generate measuring reports.

The measurement of the R_A was done under the same conditions as a video recording by the vehicle camera system. It means they were not cleaned or dried as in the requirements for manufacturers in the Czech standard ČSN EN 12899-1 (2007). This was done specifically in order to get results close to reality.

Video recording by the vehicle camera system

In order to eliminate the influence of ambient temperature and relative humidity (Khrapova, 2019), the recording of traffic signs by TSDR system was made under the same weather conditions and with the same temperature range.

The passenger car equipped with a TSDR system was selected for purpose of this research. The name of the car brand, as the type of installed camera systems, is not provided in this study since this car and research made is topic a commercial product development.

The selected TSDR system uses the monochromatic fixed focus multi-function camera that is mounted on the windscreen in front of the rear-view mirror. The camera scan and detect the traffic signs on the current section of the road. A picture processing module searches the scanned pictures for known traffic signs and compares the results with the Columbus or Amundsen navigation data.

An image processing module inspects the images captured for the speed limit and no-passing signs, some prohibitory signs as well as the signs announcing the end of the respective restriction. The traffic signs are shown as pictograms in the multi-functional display and/or the navigation system display since the validity of the sign. That is mean, the picture of the traffic sign is displayed after the car has passed the install location of the traffic sign.

The current TAS system is aimed at recognizing certain classes and types of traffic signs. The accuracy of recognition is more important than the RD for this system. Nevertheless, the picture processing module allows to detect and recognize a large number of types of road signs. For example, the ADTF development environment enables playback of stored data from camera memory, data processing and visualization.

The accuracy of recognition and RD of traffic signs were determined using the ADTF environment and visualization filters (Fig. 4).

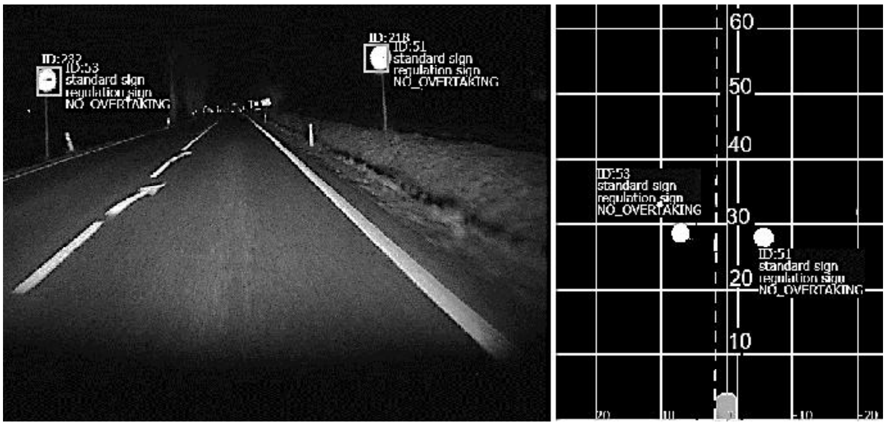

Figure 4. The screen view of two visualization filters of ADRF. (Left) Video widget with the filter of recognition all traffic signs. (Right) Coordinate graph for determining RD of the signs. Source: ADTF development environment.

Data analysis

Given a large number of identified values and traffic sign's characteristics, a summary and grouping of statistical data were carried out. Grouped data allowed to apply descriptive statistics and to test the normality of data. *Kolmogorov–Smirnov* and *Shapiro–Wilk W* tests were used to control normality of datasets. The 'STATISTICA' software was used for all kind of statistical tests.

The dispersion analysis was used to present and interpret the variation of the numerical range of RDs. Range, mean, standard deviation, coefficient of variation were calculated.

T-test for independent samples was used in order to determine whether there is a statistically significant difference between the means in two unrelated groups of one independent, categorical variable. Using this test was controlled if the positioning of the sign (vertical and lateral) and the number of signs on the post have an influence on the RD.

Main effect *ANOVA* and factorial *ANOVA* were used in the case of two independent variables and one dependent variable (RD). The datasets were controlled for normality and homogeneity of variance (*Levene's* test). Factorial *ANOVA* was used in cases where the interaction between variables was supposed to be high.

For all tests, the null and alternative hypotheses were defined as follows:

H_0: no difference in means of RD between two or more (in the case of *ANOVA*) data sets.

H_1: the average values of RD between two or more (in the case of ANOVA) data sets is significantly different.

The null hypothesis for the performed tests can be rejected if the obtained *P*-value is lower than 0.05. In order to control the family-wise error rate and to figure out which impact has considerable influence on the RD, the *Tukey's* honestly significant difference post hoc test was carried out at the significance level of 0.05.

RESULTS AND DISCUSSION

As part of the establishment of an informational database, it was found 3 signs were recognized, but the RD was not determined by ADRF. These signs were direction road signs and additional panels. The level of retroreflection in 2 cases was significantly higher than the established minimum, 1 sign did not meet the requirements for reflective properties of signs. The above-mentioned signs were removed from subsequent statistical analysis.

There were also 4 road signs were not detected and 3 signs, whose R_A was below the mandatory minimum retroreflection level. These signs were excluded from the dispersion analysis and *t*-tests for independent samples.

The dispersion analysis

The RD is a dependent variable for all subsequent statistical tests; therefore, it is necessary to understand the variation of the measurements among themselves and around the average value. The main measures of dispersion for 89 variables were found and presented in Table 2.

Table 2. The main measures of dispersion analysis for the variable of RD

N [-]	μ [m]	*Minimum* [m]	*Maximum* [m]	*Variance* [m^2]	*SD* [-]	*Coefficient of variation* [%]
89	41.7	13,0	63.0	133.7	11.5	27.6

Table 2 shows that the average RD was 41.7 ± 11.5 m and data extremely varied (coefficient of variation is more than 20%). The high value of the coefficient of variation proves the existence of factors affecting this variable.

T-test for independent samples

All studied factors can be divided into two groups: properties of the sign's surface and other characteristics of the sign (e.g. the position of the sign in space and the number of signs on the post). In order to determine the influence of factors from the first group, it is necessary to exclude the influence of factors from the second group, i.e. check whether they have a statistically significant effect on the results of recognition of road signs.

The distance from the roadside edge (lateral positioning) to the sign post, location relative to the road (on the left or right side) and the number of signs on the post have been tested using three different *t*-test. Different separate tests were carried out because of a different number of samples that were tested. Before carrying out the tests, all variables conformed to the assumptions of normality (*Shapiro–Wilk test W* test, $P > 0.05$; *Kolmogorov-Smirnov* test, $P > 0.2$).

All signs were divided into two groups according to their lateral positioning (Table 3). According to the Czech standard (TP 65 Principles for traffic signs on communications, 2013), the sign should be located no further than 2 meters from the roadside edge. Thus, all signs were divided into two groups by lateral positioning: signs that correspond to TP 65 and signs that do not correspond to standard. *T*-test for independent samples was used to compare RD for signs that correspond or do not correspond with the Czech standard (TP 65, 2013).

Table 3. Grouping parameters by three factors that are not characteristics of the sign surface

Distance from roadside edge to post		Location relative to the road		Number of signs on a post	
[m]	group number	[-]	group number	[-]	group number
≤ 2	1	left	1	1	1
>2	2	right	2	2	2

From the results presented in Table 4, it can be concluded that there is no significant difference in RDs, since $P > 0.05$.

Table 4. The results of T-test for independent samples that are represented the main statistical parameters for three factors

Parameter	*p-value*	*d*	*t-value*	*df*	Group number 1			Group number 2		
					μ	*N*	*SD*	μ	*N*	*SD*
Lateral offset	0.06	0.5	1.9	87	45.5	41	4.1	41.3	46	12.3
Siting	0.14	0.6	-1.5	23	50.7	13	8.1	46.2	12	6.6
Number of signs	0.003	0.8	3.1	65	44.7	38	9.8	35.6	28	11.9

The results of the first test are unexpected since presumably the accuracy of detection and recognition traffic signs located far enough from the road might be low. The medians of these two groups do not statistically different from each other but the range of RDs is not similar (Fig. 5). The box plot of Fig. 5 more clearly demonstrates the range of values in two groups.

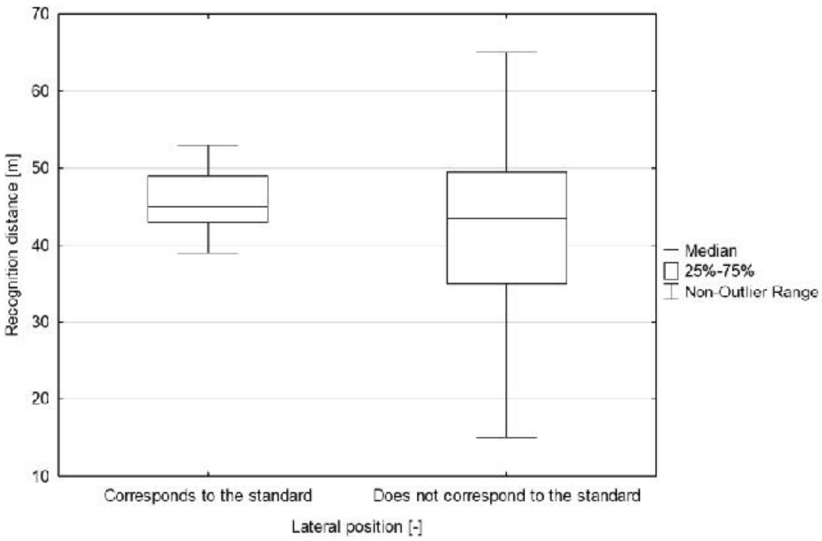

Figure 5. The box plot of RDs grouped by lateral position.

The duplication of road signs on the left-hand side of the road is not typical for all categories of signs. In the framework of this work, only the ‘no overtaking’ sign was located both on the right-hand and the left-hand of the road. Therefore, the influence of the location relative to the side of the road was tested only for this type of road sign. The T-test of two independent groups was used in order to determine whether there is a statistical difference in the RDs between signs on the right-hand and the left-hand of the road. The most important results are shown in Table 4. As can be seen from the table, the p-value is much higher than the significance level of 0.05 that means there is no difference in means between two examined groups.

The third t-test was conducted to analyse the influence of the number of signs on their RD. The number of signs on the single support varied on the selected road sections. One, two or three signs were installed on the one post. The number of posts with three of signs was not large enough, that it is why only posts with one sign, or two signs were analysed. The results are also presented in Table 4. Contrary to previous results, the null hypothesis for the performed tests can be rejected because the obtained *P*-value is lower than 0.05.

Another additional t-test was carried out to determine if there is a difference in the level of retroreflection of two road signs located on the same post. The means of R_A values between two signs were statistical equal (367 ± 110 m, N = 14 vs, 317 ± 70 m, N = 14; $P = 0.34$, $df = 25$, $d = 0.6$).

The decrease in the RDs can be explained by the non-standard reflective area, which is formed due to traffic signs that are closely adjacent to each other and have almost the same retroreflective level. The example of this problem is demonstrated in Fig. 6. A conditional division of the recognition process into 3 stages shows that during the first stage the shape of the sign was determined incorrectly, the same as the code of the sign. In the second stage, the determining area was divided into two and in the third stage, the traffic signs were correctly recognized (correct codes were attached).

Figure 6. The problem in recognition of two traffic signs on a post is demonstrated in three steps. Source: Adopted from the ADTF development environment[1].

Two tests are demonstrated there is no correlation between the RD and the position of the sign relative to a road. The third test revealed a significant impact of the number of traffic signs (on a single post) on the RD.

The effect sizes of all four tests were medium (for first, second and additional tests) and high (for the third test), which gives an indication of sufficiently high reliability of the results.

ANOVA

The main effect ANOVA was used to determine the influence of properties of sign surface on its RD. The highest R_A value (in most cases white background sheeting), the

[1] Remark: text edited by authors of paper

area of colour with the highest R_A and the contrast of the sign have been selected for the analysis.

The signs that were not detected were included in the analysis (RD = 0) since their retroreflective level was higher than 0. Also, the signs with the R_A below maintained retroreflectivity level were taken into account. Despite the discrepancy with Czech standards, these signs (2 directional and 1 prohibitory) were recognized from more than 30 meters.

Only signs that are alone on the post are analysed since the variable of RD is sensitive on the number on the signs on the post and because of the inability to evaluate the individual parameters of the sign when two signs are so close to themselves.

The area of colour was divided into two groups: the value of the area of colour is less or equal to 50% and the value of the area is higher than 50%. The values of contrast were also divided into two groups: $C \leq 1.0$ and $C > 1.0$. The R_A values were separated into four ranges: 0–150, 151–300, 301–450, 451–600 cd lx 1 m^{-2}. This grouping allowed to normalize datasets.

Table 5. The results of multifactorial main effect ANOVA that are presented as main statistical parameters for such factors of sign surface as area, contrast and coefficient of retroreflection

Factor	*Df*	*F-value*	*P-value*	η_p^2
Area of colour	1	0.41	0.53	0.01
Contrast	1	15.49	0.00[1]	0.28
R_A	3	7.29	0.00[1]	0.35
Error	40			

[1] – values lesser than three decimal places after the decimal point was neglected.

All variables conformed to the assumptions of normality (*Shapiro–Wilk test W* test, $P > 0.05$) and homoscedasticity (*Levene's* test, $P > 0.05$).

The results of multifactorial *ANOVA* are presented in Table 5.

The test indicated that the variables with the significant effects on the RD were the R_A and contrast. The size of the area with the highest R_A of the sign was not found to be statistically significant in the case of the one sign on the post.

The interaction of contrast and R_A values were controlled by the factorial ANOVA that indicated the considerable effect of this pair of variables on RD (Table 6).

Table 6. The results of factorial ANOVA that are presented as the main statistical parameters of interaction between contrast and coefficient of retroreflection of sign surface

Factor	*Df*	*F-value*	*P-value*	η_p^2
Contrast	1	18.57	0.00[1]	0.33
R_A	3	17.89	0.00[1]	0.459
Contrast x R_A	3	5.16	0.00[1]	0.249
Error	38			

[1] – values lesser than three decimal places after the decimal point was neglected.

The graphic result of General linear model is shown in Fig. 7. On the plot, there are two non-parallel lines that prove the statistically significant interaction between R_A and contrast. For the range of R_A from 0 to 150 cd lx^{-1} m^{-2} and $C \leq 1$ the RD is the lowest and the values are dramatically different from another.

Tukey's post hoc test was carried out to understand what combination of factors has considerable influence on the RD. Only above mention, a combination of R_A values and contrast has a significant effect on the RD.

As can be seen from Fig. 7, the RD increases with the increasing the R_A values. It was expected that brighter traffic signs (means with high R_A) are recognized faster than signs with low R_A values (less than 150 cd lx^{-1} m^{-2}). An unanticipated development was that for the traffic signs with the contrast lower than or equal to one with R_A above 450 cd lx^{-1} m^{-2} RD decreases. This can be explained by 'overglow' effect that was discussed by Schnell et al. (2004) and Batchelor & Sauter (2013).

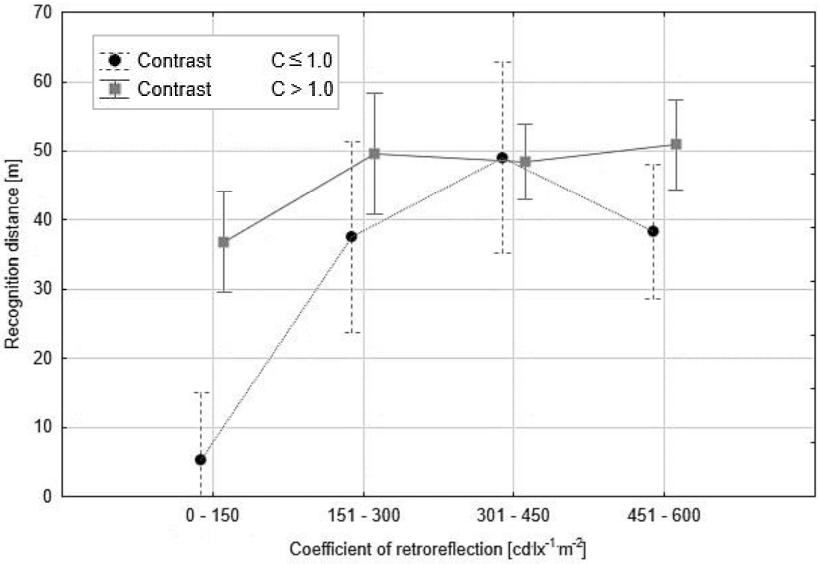

Figure 7. The combined effects of contrast and coefficient of retroreflection for the case of one sign on a slope.

In both analysis the highest η_p^2 values (35% and 59%) were for R_A that means the highest retroreflective level is the most important main effect. However, the combination of R_A and contrast has also significant effect in the RD, since the η_p^2 is higher much higher than 14%.

To determine how the coefficient of determination was found. R^2 for main effect ANOVA was 0.75 and for factorial *ANOVA* is 0.82. That means that the second model better explained the variation of data.

CONCLUSIONS

The traffic sign database is one of the key points necessary for the training of modern TSDR systems. The lack of public and well-structured databases is a significant obstacle in this area of research. One of the solutions is creating models of sign scenes that are close to real conditions based on knowledge of the laws and characteristics of the traffic signs. Technical regulations determine the limits for the use of road traffic signs that have certain characteristics on a certain type of roads. Knowledge of the influence of sign parameters on RD will predict the effectiveness of the whole TSDR system.

The main goal of this study was to determine which of the parameters or traffic sign characteristics ha a significant impact on the performance of the TSDR system, especially at night, when the number of accidents doubles (National Safety Council, 2018). In this paper, RD was chosen as a parameter for evaluating the effectiveness of the TSDR system, since it is important not only whether the sign was recognized, but also how long does it take to this system to recognize traffic sign.

Number of exposure years, location relative to the road, orientation, class of retroreflective sheeting and the R_A were determined for 100 signs. For most of these signs (65%), the average exposure was 3 years, the level of retroreflection was equal to class R_{A2}, the orientation of the signs was to the West.

During data processing, it was noted that for some signs lateral offset does not correspond to the Czech standards. Unexpectedly, the statistical analysis did not reveal a statistical difference between the signs that do and do not correspond to the standard. There was no statistical difference between the signs on the left-hand side and right-hand side of the road.

On contrary, the number of signs on the post (one or two) has an effect on the RD. Especially if the signs have the same level of retroreflection, thereby forming an atypical area for determination. Based on this, a recommendation for local road agencies can be made: 'For two or more signs on the same post the R_A of each sign should be different in the way that the value of retroreflective contrast should be more than 1'.

In view of the foregoing, the influence of the coefficient of retroreflection was assessed only for signs located singly on a post. A significant difference was found in the RDs for a group of signs with the highest value of R_A below 150 cd lx^{-1} m^{-2} and the internal contrast lower or equal to 1. However, these values indicate that such signs do not meet Czech standards and should be removed by the relevant road authorities.

It is necessary to remark that all unrecognized signs (only 4) were information road signs; their number of exposure years was not determined since there was no corresponding marking on the signs. The retroreflective surface was damaged, presumably from corrosion, and the R_A was much lower than the minimum level. It can be assumed that these signs were posted before 2004 when the Czech Republic adopted a standard obliging signs' manufacturer to place markings on the sign.

In conclusion, the efficiency of recognition of approved traffic signs (declared by the car manufacturer) was 100%.

The results and conclusion of the paper support the necessity of the further research. The property influence of traffic signs on the efficiency of recognition by TSDR system will play very important role in traffic control and road safety in a future.

ACKNOWLEDGEMENTS. The author gratefully acknowledges that the present research was supported by the Internal Grant of Faculty of Engineering, CULS Prague (grant number IGA 2019:31170/1312/3113).

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