Acquisition and analysis of light intensity and light beam length in passenger motor vehicles

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Abstract: *The primary task of daytime running lights is for road users to perceive the presence of vehicles, as well as other road users, which is a basic prerequisite for safe traffic. The visibility of the vehicle, as well as of other road users, depends on the light intensity and light beam length of passenger vehicles. As the impact of daytime running lights on improving road safety has not been fully researched, in this paper the lights intensity and length of the light beam in passenger motor vehicles was measured and analysed. The research was done during the technical inspection of the vehicle (at the "Tachograph" technical inspection in Kragujevac). The results show that low beams are more efficient in illuminating the road compared to high beams, while there is no significant difference in light intensity between left and right vehicle headlights.*

Keywords*: MEASUREMENT, INTENSITY, LENGTH, LIGHT BEAM*

1. Introduction

The impact of daytime running lights on improving road safety has not been fully researched [1]. The primary task of daytime running lights is for road users to perceive the presence of vehicles [1, 2], as well as of other road users, which enables successful and timely interaction of road users, which is a basic prerequisite for safe traffic.

Scandinavian countries were the first to introduce the use of daytime running lights on motor vehicles. Finland introduced the mandatory use of daytime running lights during the winter period, on roads in rural areas, at the beginning of 1972. Sweden introduced the mandatory use of daytime running lights for all vehicles, throughout the year, in 1977. Since 1985, Norway has mandated the mandatory installation of automatic daytime running lights on new vehicles. Looking at the advantages and disadvantages of countries with previous experience of using daytime running lights, most developed countries have accepted daytime running lights as a necessary measure to improve road safety [2]. Montenegro is one of the first countries in the Western Balkans to introduce the mandatory use of daytime running lights in 2012 [3]. In Serbia, with the introduction of the new Law on Road Safety [4], the mandatory use of daytime running lights was introduced (2009 year) [2]. The percentage of use of daytime running lights in Serbia in 2014 was 95.8%, while the use of daytime running lights increased in 2015 to 97% [5].

Research conducted in 2012, in which the correctness of passenger vehicles was analysed, found that during an emergency inspection of 10,000 vehicles, 39% of the vehicles were technically defective. The observed defects refer to systems that are essential for the safety of road users (steering system, stopping system, lighting system). The lighting system was defective in 30% of the analysed vehicles [6].

Papers regarding the impact of daytime running lights on improving road safety have been publishing since the end of the 20th century [7-10], and the contribution to the improvement of this topic can be seen in the papers of more recent dates [11-13]. Various studies on the effects of daytime running lights on road safety have been carried out for bicycles and motorcycles [2,12-14]. At the same time, research began on the effect of daytime running lights on increasing the road safety in passenger vehicles as well [2, 7-9].

The impact of the visibility of road users on road safety is obvious. So, the further the driver is able to see obstacles or other road users, the more time he has available to avoid a road crash. One of the main reasons for the occurrence of road crash is the late perception of other road users. Research shows that only 5% of drivers notice a pedestrian wearing dark clothes on the side of the road in conditions when the vehicle's "low" beam is on, as well as with a vehicle in the opposite direction in a passing situation [15].

The first research concluded that vehicles with daytime running lights were less likely to be involved in road crashes compared to vehicles without daytime running lights. However, no significant statistical relationship was found between the use of daytime running lights and participation in road crashes [15-16]. Ivanišević et al. [2] indicated in their research that there is a statistically significant difference in the estimation of motorcycle speed when the daytime running lights are on/off and when the daytime running lights with the led system are on. Errors in the estimation of motorcycle speeds are particularly pronounced at higher speeds, at 70 and 90 km/h, where one can come to the conclusion that the use of daytime running lights with the LED system has a greater contribution to the perception and estimation of motorcycle speed on the roads in the settlement and outside the settlement, that is, on roads with a higher speed limit (50, 70 and 90 km/h). Ivanišević et al. [2] indicated that there are statistically significant differences in the estimation of vehicle speed when daytime running lights are on and when daytime running lights are off, as well as the relationship between the number of years of driving experience, frequency of driving, participation in road crashes, and other demographic characteristics of the respondents.

Considering all of the above, as well as the limited number of studies analysing light intensity and beam length in passenger vehicles, this paper presents research and analysis on these factors in passenger motor vehicles.

2. Methodology

2.1. Description of the measurement system and preparation of the research site

A device called a "regloscope" was used to measure the length of the light beam, as well as the light intensity of passenger motor vehicles. "Regloscope" is a device for testing every type of vehicle light beam [17]. The basic parts of the "regloscope" are: base with wheels (base on floor rails-sliding movement), device column, vertical moving system of the optical box, optical box, column with divisions, visor aiming system and visor (Fig. 1). The device can be installed on floor rails (with the possibility of sliding movement) or on a stand with PVC wheels. The optical box is adjustable in height via a sliding system made of plastic sliders that move on a deeply drawn aluminium column. Centimetre graduations are drawn on the column to facilitate proper adjustment of the optic box to the vehicle's light beam. Visor with a retackle or visor with a mirror, allow the device to be adjusted strictly according to the vehicle [18].

Preparing the vehicle for measuring the light beam, as well as the light intensity, means that the headlights of the vehicle must be cleaned and dry. It is necessary that the vehicle is placed on a flat surface, avoiding any hindrance in terms of: snow, ice, mud, sand and the like. The wheels of the vehicle must be pointed straight, in line with the body of the vehicle, i.e., the steering wheel must be in the neutral position. The vehicle must have the recommended tire pressure. At the time of measurement, the back seat of the passenger vehicle (if there is any) must be loaded with 70 kg, i.e., with one passenger. The vehicle engine must be turned on during the experiment [17].

The measurement can be carried out in an open or closed space. If the measurement is conducted indoors, it is necessary, due to the running vehicle engine, to have an appropriate exhaust gas extraction system [17]. The horizontal surface at the measurement location must be flat. If that is not possible, the maximum allowable slope is 0.5%. Therefore, it is not suitable to conduct measurements on irregular or uneven surfaces [17].

Fig. 1 *Regloscope*

Fig. 2 *Example of the work environment, horizontal surface, and the relative positioning of the vehicle and the "Regloscope"*

During measurement, the "Regloscope" should be positioned 20 to 65 cm from the vehicle (Fig. 2) [17]. The height of the optical box should be set so that the centreline of the headlight aligns with the centreline of the optical part of the box. On the front side of the optical box, there are two notches (Fig. 3) that indicate the centreline of the optical box, which should align with the centreline of the headlight (Fig. 4) [17].

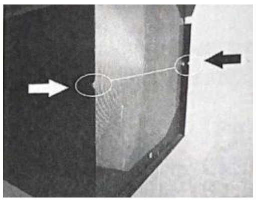

Fig. 3 *Display of the centreline of the optical box (Marinković Hofmann)*

Fig. 4 *Display of the mutual positioning and alignment of the central lines of the optical box and the headlight*

For proper positioning of the optical box, in addition to the method previously mentioned and described, it is also possible to position the optical box by measuring the height from the floor to the centreline of the headlight and then adjusting the optical box to the same height [17]. If the height of the centreline is known from the manufacturer, the height of the optical box can also be adjusted using the graduated scale on the column of the "Regloscope" [17]. Adjustment can be made using the adjustment system with a sight and a level (bubble). Adjustment using a sight can be done with a mirror sight or a thread sight. Regardless of the type of sight, the method for positioning the "Regloscope" relative to the headlights is identical. Thus, it is necessary to find two horizontal points on the front part of the vehicle (for example: headlights, hood, points on the windshield, etc.). These two points should align with the line on the mirror sight or with the thread on the sight. By moving the "Regloscope" it is possible to align it with one of the specified points. When the points align, the optical box is correctly positioned relative to the vehicle [17].

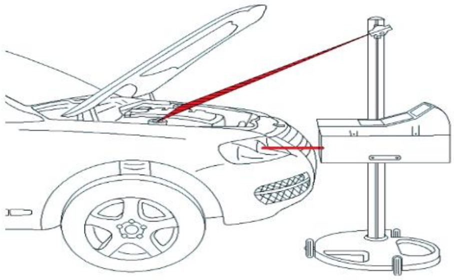

Fig. 5 *Method of positioning the Regloscope using a visor [18]*

It is necessary to check the level (bubble) placed inside the optical box, on the base, which is visible through the transparent panel on the top, to ensure that the optical box is positioned horizontally. If the bubble is not centred in the level, it is necessary to loosen the handle on the optical box and adjust the optical box up/down until the bubble is centred in the level of the optical box. After that, tighten the handle [17]. If the "Regloscope" is mounted on wheels, after adjusting the "'Regloscope" for one headlight of the vehicle, it is necessary to repeat the adjustment for the other headlight or for the fog light [17]. After preparing the vehicle and the work environment for measurement, as well as positioning the vehicle and the "Regloscope" in the defined relative position, the conditions are set for conducting the experimental research or measurement.

2.2. Conducting experimental research

The alignment of the headlights measured by the "Regloscope" is expressed as the percentage ratio between the height of the headlights and the length of the illuminated path of the low beams [19]. Since it is not possible to measure the length of the low beam light (D) or the length of the road illuminated by the low beam headlight during the technical inspection, the alignment of the lights is measured using the "Regloscope". Based on this data, the length of the low beam light can be determined, or it can be verified whether it is within the prescribed limits [19]. Considering the above, the length of the low beam light can be calculated as the percentage ratio between the height of the headlights and the alignment of the headlights [19]. The alignment value of the headlights can be defined in two ways. The first way is the value defined by the vehicle manufacturer, which is either printed on the upper part of the outer headlight or provided in the vehicle's user manual. If it is determined that the alignment value is indicated on the headlight or in the user manual, this value must be set on the scale of the control for positioning the projection screen (by adjusting the knobs on the back of the "Regloscope"), and then it is determined whether the boundary between the illuminated and shaded areas on the "Regloscope" projection screen aligns with the cut-off line [19].

After adjusting the knobs for the headlight alignment value to the value defined by the manufacturer, if the boundary of the illuminated zone is below the cut-off line, it is necessary to turn the knobs to determine whether this difference is within the tolerance limits. If it is not, the "Regloscope" knob should be turned until the boundary between the illuminated and shaded zones on the "Regloscope" projection screen aligns with the cut-off line, which represents the second method for defining the headlight alignment value. After that, the alignment value is read from the knob scale, and based on this value and the measured height of the headlight centre, the length of the low beam light is calculated [19].

The boundary between the illuminated and shaded zones on the panel for asymmetric lights, which are the most common today, extends from the left side as a horizontal dashed line to the centre of the panel, and from the centre, it rises at an angle of about 15º from the horizontal line, with the illuminated zone being the area below this line.

Fig. 6 *Alignment of low beam lights (asymmetric headlights)*

There are analog and digital light intensity meters. With an analog meter (Fig. 7), as soon as the low or high beams are turned on, the light intensity value can be read from the luxmeter scale and its correctness assessed. The light intensity value read from the first scale is measured in lux, while the value on the second, or average scale, can be read in candela. If the device has a digital light intensity meter, the check is performed by turning on the low beams on the vehicle, pressing the button, and reading the intensity on the luxmeter (Fig. 8).

Fig. 7 *Analog light intensity meter*

Fig. 8 *Digital light intensity meter*

2.3. Data collection and processing

The Taguchi method was applied to analyse the length of the vehicle's light beam and the light intensity, specifically to analyse the impact of direct factors on the length of the vehicle's light beam and the light intensity. In the MiniTab 21 software program, an experimental plan was set up, and a design matrix was defined, considering the defined control factors (country of origin of the vehicle, vehicle age, vehicle weight, vehicle height, and vehicle power) and levels. The control factors in this study were selected arbitrarily by the author, as well as based on previous research [19], which represents a limitation of this study. Additionally, another limitation of this study is the fact that data on the structure and quality of the vehicle's headlights were not taken into account during the research due to technical constraints.

The results of the matrix concerning the length of the low and high beam light, as well as the intensity of the low beam light for the left and right headlights of the vehicle, were obtained through experimental research based on the defined design matrix. The defined design matrix, including the specified factors and levels, as well as the measured values of the matrix results, were entered into the software program. To minimize measurement error for each experimental point, three measurements were taken for each point (including two repeated measurements), and then the average result was calculated. The obtained average values of the results from the design matrix were used to analyse the results related to the length of the low and high beam light, as well as the intensity of the low beam light for the left and right headlights of the vehicle.

After forming the database in the software program, data analysis and validation were performed, followed by statistical processing of the design matrix data. The analysis of results, using the Taguchi method, was carried out in the MiniTab 21 software program. Statistical analysis of the data was performed using the IBM SPSS Statistics v.26 software package, employing standard descriptive statistics methods (mean, median, mode, variance, standard deviation, minimum, maximum), as well as the statistical methods described below. The normality of distribution was tested using histogram inspection and the Kolmogorov-Smirnov test. Since the distributions of all analysed variables do not follow a normal distribution, non-parametric methods were used. The significance of the differences was assessed using the Wilcoxon Signed Ranks Test.

A null hypothesis (H_0) was set, which states: There is no statistically significant difference between the groups, and an alternative hypothesis (H_a) which states: There is a statistically significant difference between the groups. The significance level (α) was set at 5%. Therefore, if $p \leq 0.05$, H_0 is rejected and H_a is accepted, while if $p > 0.05$, H_0 is accepted.

3. Results

The frequency distribution of the results for the length of the road illuminated by the vehicle's low beam light indicates that the highest percentage of vehicles participating in the study illuminate the road with a low beam light length of 67 meters, accounting for 14.8% of the vehicles.

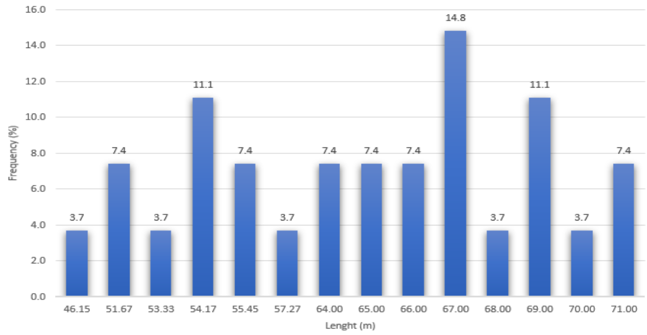

Fig. 9 *Frequency distribution of the results for the length of road illumination with the vehicle's low beam light, in percentages*

The highest percentage of vehicles participating in the study illuminate the road with a high beam light length of 67 meters, accounting for 25.9% of the vehicles.

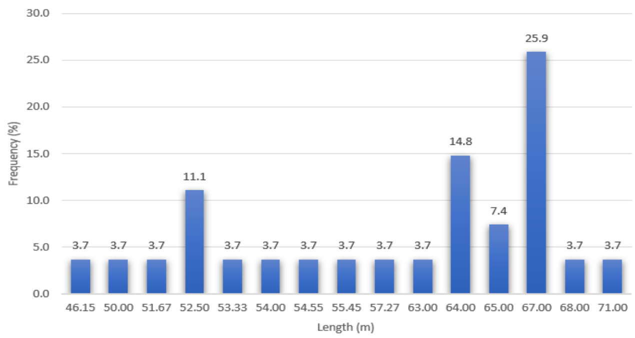

Fig. 10*. Frequency distribution of the results for the length of road illumination with the vehicle's high beam light, in percentages*

The results of the descriptive statistics indicate that the mean length of road illumination with the low beam light (M (mean)=62.17; SD (standard deviation)=7.33) is greater than the length of road illumination with the high beam light (M=60.63; SD=7.09).

***Table 1:** Descriptive statistics of the results related to the length of the light beam*

Descriptive statistics	Light beam length (*m*)	
	"low" beam	"high" beam
N	27	27
Mean	62.17	60.63
Median	65.00	64.00
Std. Deviation	7.33	7.09
Minimum	46.15	46.15
Maximum	71.00	71.00

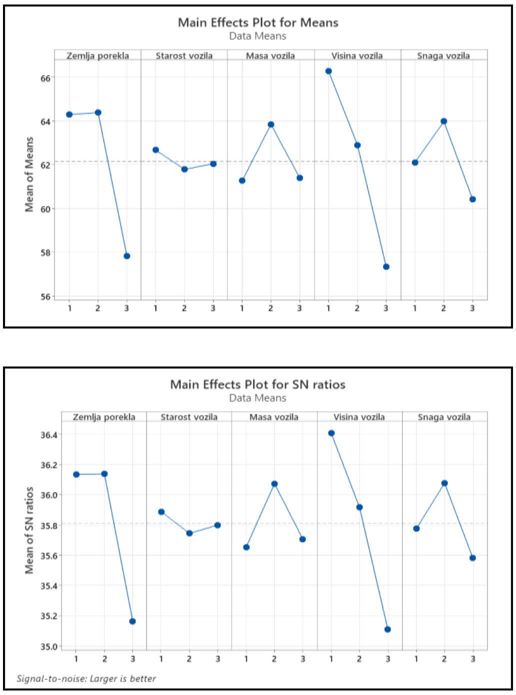

***Fig. 11** Analysis of the optimally set factors for the maximum length of the "low" beam, using the Taguchi method*

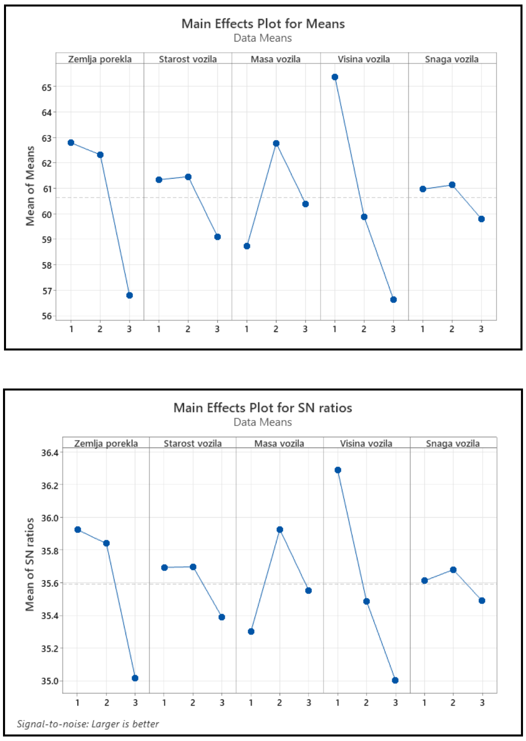

***Fig. 12** Analysis of the optimally set factors for the maximum length of the "high" beam, using the Taguchi method*

The potential relationship between the length of illumination with the low and high beam lights on the vehicle was tested using the Wilcoxon Signed Ranks Test, and statistically significant differences were observed between the length of road illumination with the low beam lights and the high beam lights on the vehicle (F=-3.414; p=0.001).

The frequency distribution of the road illumination intensity results from the low beam light of the left headlight indicates that the highest percentage of vehicles participating in the study have an illumination intensity of 4 lux, accounting for 25.9% of the vehicles.

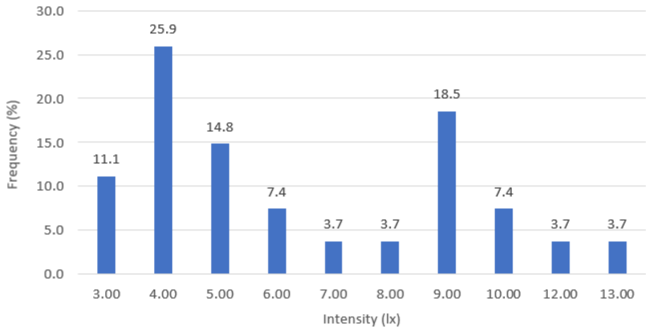

***Fig. 13** Frequency distribution of the results for the intensity of road illumination with the low beam light of the left headlight of the vehicle, in percentages*

The results of the road illumination intensity from the low beam light of the right headlight indicate that the highest percentage of vehicles participating in the study have an illumination intensity of 4 lux, accounting for 22.2% of the vehicles.

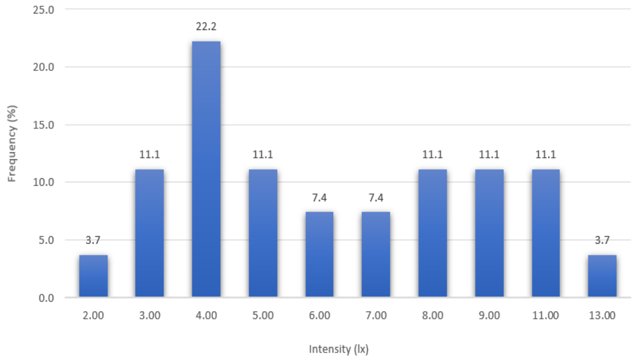

***Fig. 14** Frequency distribution of the results for the intensity of road illumination with the low beam light of the right headlight of the vehicle, in percentages*

The arithmetic mean of the light intensity on the left headlight is M=6.44; (SD=2.91), while on the right headlight is M=6.41; (SD=2.98).

***Table 2:** Descriptive statistics of the results related to the light intensity*

Descriptive statistics	Light intensity	
	Left headlight	Right headlight
N	27	27
Mean	6.44	6.41
Median	5.00	6.00
Std. Deviation	2.91	2.98
Minimum	3.00	2.00
Maximum	13.00	13.00

The potential relationship between the intensity of the light from the left and right headlights of the vehicle was tested using the Wilcoxon Signed Ranks Test, and no statistically significant differences were observed.

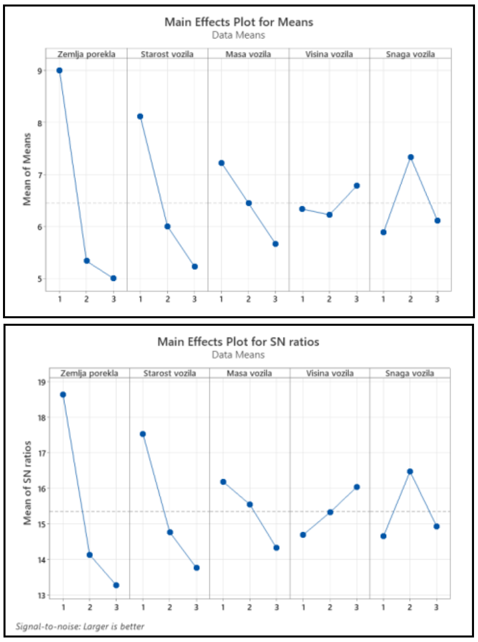

Fig. 15 *Analysis of the optimally set factors for the intensity of the "low" beam of the vehicle's left headlight, using the Taguchi method*

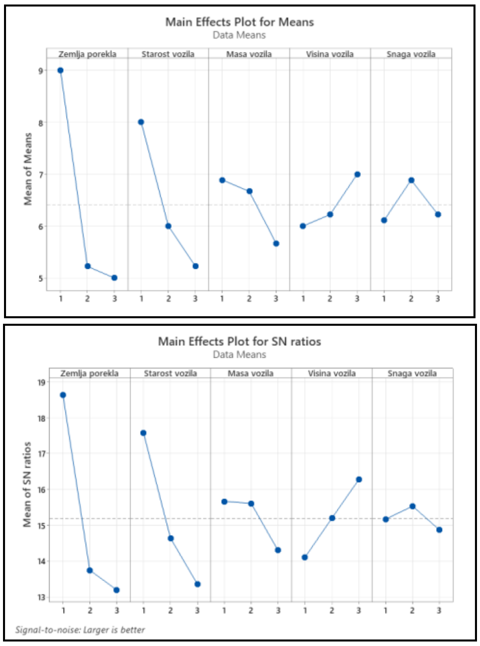

Fig. 16 *Analysis of the optimally set factors for the intensity of the "low" beam of the vehicle's right headlight, using the Taguchi method*

4. Conclusion

Based on the data collected and analysed in the conducted research, the following conclusions can be drawn:

- The results of the mean length of road illumination with the light beam indicate that the length of the road illuminated by the low beam light (M = 62.17; SD = 7.33) is greater than the length of road illumination with the high beam light (M = 60.63; SD = 7.09);
- The results of the mean light intensity on the left headlight are M = 6.44; (SD = 2.91), while on the right headlight, it is M = 6.41; (SD = 2.98);
- The relationship between the length of road illumination with the low and high beam lights on the vehicle was tested using the Wilcoxon Signed Ranks Test, and statistically significant differences were observed between the length of road illumination with the low beam lights and the high beam lights on the vehicle (F=-3.414; p=0.001);
- The study also included an analysis of the potential relationship between the light intensity on the left and right headlights of the vehicle, using the Wilcoxon Signed Ranks Test, and no statistically significant differences were observed.

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