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ANALYSIS OF OPERATING SPEED DEVIATIONS FROM LIMIT VALUES ON TWO-LANE ROADS

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Abstract

The main goal of speed management is to provide harmonized traffic flow conditions, i.e. to achieve a balance between traffic flow safety and efficiency. One of the most important management measures for achieving this goal is reflected in defining a credible speed limit that would allow maximizing the service level capacity of the observed section, i.e. minimizing user costs and accident risk. Reaching optimal speed credibility is an imperative in road engineering, thus ensuring continuous traffic flow. The aim of this paper is to analyze the suitability of posted speed limits and drivers' compliance with them on a section of the main two-lane road M-I-108, Klupe – Teslić (Barići). The research indicates the inadequacy of posted speed limit credibility on the observed section, and it is concluded that in addition to a primary function of achieving the required level of safety, the speed limit must be in accordance with the functional classification of the road within the network, technical and exploitation characteristics and the environment.

Key words*: limit credibility, operating speed, speed management*

1 INTRODUCTION

In this paper, it is performed an analysis of the credibility of posted speed limits, which is extremely important taking into account the fact that improper and unadjusted speed creates a number of negative impacts. A credible speed limit is defined as a speed limit that is in accordance with driver's perception influenced by road and traffic conditions.
Operating speed is an initial program parameter which is essentially an indicator of a service level of a certain road under relevant traffic load and should actually reflect real traffic flow conditions under relevant traffic load [1].
Speed limit values have a significant influence on the values of reached speeds in traffic flow. The new concept of speed limit credibility analysis is based on the analysis of operating speeds as a function of different traffic flow classes. It has been determined that speed values obtained in this way are closer to the values of the 85th speed percentile and to the speed values of drivers within a target group (drivers exceeding the speed limit up to 10 km/h) which should be focused on, and which need to be adjusted to the speed management system [2].
When the speed limit is defined as a function of traffic safety or adapted to the characteristics of the environment, but not to technical and exploitation characteristics and characteristics of traffic flows, there is a large percentage of exceeding the speed limit, and there are large speed dispersions in traffic flows [3].
By increasing a speed limit, traffic participants' compliance with it increases too, and thus there is an increase in roadway capacity due to the higher speed of vehicles on the road [4].
The results of the research in terms of compliance with speed limits on the main roads in the Republic of Srpska, conducted by the Auto-Moto Association of the Republic of Srpska in 2014, confirm that there is non-compliance with speed limits on main roads in the Republic of Srpska, which leads to a conclusion that the posted speed limits should be reviewed and adjusted to the requirements of safe traffic flow and mobility.

2 RESEARCH METHODOLOGY

For the purposes of this paper, an activity plan has been defined, i.e. an algorithm for conducting a speed limit credibility analysis, which consists of the following steps:
- defining a research area, research time and a sample,
- determination of technical and exploitation characteristics of the road section,
- measurement of operating speeds (local measurement method) and
- data analysis and data synthesis.

The measurement was performed during three days from March 23 to 25, 2021, in the period from 8 a.m. to 4.30 p.m. on a section of the main two-lane road M-I-108, Klupe – Teslić (Barići).
On the Klupe – Teslić (Barići) section, the speed limit is defined by an explicit order traffic sign, "speed limit - II-34" and it is 50 km/h. This section, with a total length of 16.734 km, is located on hilly and mountainous terrain. The analyzed section is characterized by an average annual daily traffic of 6579 veh/day (data from 2016) and satisfactory technical and exploitation characteristics.
The total width of the road on the entire Klupe – Teslić (Barići) section is 7 m (two traffic lanes of 3.5 m width), the road is in very good condition, and it was dry during all measurements. Within this section, it was necessary to measure vehicle speeds on three different longitudinal gradients (ascents/descents) of: 3.00%, 5.70% and 4.06%. Taking into account that speeds were measured separately on descents and ascents, it is clear that the survey was to be conducted at six different cross-sections. The measurement was performed on the cross-sections of observed road

segments, the length of which before a measuring cross-section was 1000 m.

At each of these cross-sections, speeds of at least 410 vehicles were recorded and the total sample for analysis was 2563 measured speeds of different vehicle classes. The classes of vehicles recorded are: PC (passenger car), BUS (bus), LCV (light commercial vehicle) and HCV (heavy commercial vehicle). The main data collection methods used for the research were a measurement method and a statistical method. As simple measurements in terms of traffic safety, we can include: measurements based on counting (number of accidents, traffic flow, number of casualties in accidents, etc.) or real measurements (amount of certain toxins in exhaust gases or air, vehicle speed, road width, curvature radii, etc.). A statistical method is an unavoidable method in traffic research and involves the processing of samples. The application of a statistical method, and especially the accuracy of findings, depends on sample creation and its quality [5]. In order to obtain the results, it was conducted the field research of speed measurements in real conditions by a Bushnell NSN 5840-01-620-6670 handheld radar. In all radar devices, speed measurement is based on the Doppler effect. A radar antenna transmits a narrow radar beam with a fixed angle towards the road orientation. If a vehicle enters the antenna radiation field, part of the radiation is reflected and received back to the antenna. Due to the movement of the vehicle, the frequency of the radiation changes in proportion to the speed of the vehicle. Accordingly, based on the difference in frequency between radiation transmission and radiation reflection, it can be calculated vehicle speed [6]. While observing, the observer systematically and in accordance with a predetermined plan registers precisely defined data and creates documentation. This documentation will serve as a foundation for later research stages (collection, organization and processing of data and their scientific interpretation). After the measurement, as part of data analysis and data synthesis, the database was created in Microsoft Office Excel v. 2010 where the data were analyzed, and graphs of relative frequency distribution of individual vehicle classes and calculation of the 85th percentile were obtained by TableCurve 2D V5.01, a statistical software package.

3 DEFINING THE PROBLEM

Speed is a stochastic quantity that may be determined only in real traffic conditions. It means that the values observed at a certain road cross-section occur with a certain probability. Based on experimental research, it has been found out that the speeds of individual vehicles, as a rule, correspond to the law of normal distribution [7].

This paper presents the distribution of speeding by vehicle classes on different slopes along the Klupe - Teslić (Barići) section. The distribution was mostly created as normal and log-normal distribution. The specific problem which is the reason for this research is that on some road segments (road cross-sections), there are inappropriate speed limits, so the question of their credibility arises.

Traffic flow speed values are predominantly influenced by [8]:

- technical and exploitation characteristics of the road,
- the degree of realization of uninterrupted flow (indirectly, node density and management method) and
- the position of the road in the network, i.e. the influence of the road environment. The number and severity of traffic accidents increase as speed increases. Non-compliance with speed limits is a very reliable indicator of the propensity for traffic accidents. Namely, drivers who drive too fast, also commit other traffic violations, and according to one research, every third driver who was fined for speeding was a participant in a traffic accident. High average speeds mean higher collision speeds too, and thus more severe consequences of accidents [9]. Speed limit exceedances are very common. The greater the difference between free and limited speed, the higher the percentage of drivers who do not comply with a posted speed limit. In Europe, in general, 40.00% to 60.00% of drivers do not comply with a posted speed limit. There are significant differences in terms of speeding on different types of roads. The highest percentage of drivers from European Union countries (28.00%) stated that they do not comply with the posted speed limit on highways, while the percentage was lower on state roads (19.00%), municipal roads (13.00%) and in urban zones 7.00%) [10]. Heavy goods vehicles and buses recorded greater speed limit compliance than cars, light commercial vehicles and motorcycles. The number of vehicles exceeding the speed limit varies depending on a road and vehicle type. On roads with a speed limit of 50 km/h, the average free speed is slightly above the speed limit for three types of vehicles (cars, motorcycles and light commercial vehicles) while the average free speed is at or below the speed limit for each vehicle type on other road types [11]. Reasons for speeding are different and can relate to temporary motives (e.g. rush), personality traits (e.g. driver's aggression), vehicle, road and environment characteristics, and safe travel speed perceptions (depending on road geometry and environment, weather conditions, etc.). The reason for exceeding the speed limit may also be that the driver is not aware of the speed limit in all traffic situations: either the speed limit sign was missing or the driver didn't notice it. In both cases, the road characteristics were not sufficiently informative about the applicable speed limit. Driving too fast can be one of the consequences of the tendency to overestimate one's own skills, underestimate risk and succumb to peer pressure. Therefore, the issue of speed and speeding should be highlighted in the education and training of young drivers [12]. Roads with wide lanes suggest higher speed limits to drivers while noticeable pedestrian walkways and proximity to residential housing are signals to reduce speed. It is important that a posted speed limit coincides with the visual appearance of the road because otherwise there is significant speeding [13]. When defining a speed limit for a relevant section, it should be taken into account its impact on the mobility, safety, environment and life quality of people living in the immediate vicinity of the road, so that the speeds are in line with the conditions prevailing on the section [1]. It can be assumed that drivers will drive in accordance with the posted speed limit if they consider it reasonable or credible. In contrast, if the posted speed limit is not in line with the limit that drivers consider appropriate according to the characteristics of the road, then it can be ignored and the entire speed management system can be called into question.

Fixed speed limits represent appropriate speeds for average conditions. On the other hand, dynamic speed limits are limits that take into account real-time traffic, road, and weather conditions. Dynamic limits are also expected to increase the credibility of speed limits in general [14].

4 RESEARCH RESULTS

The paper analyzes operating speed deviations from limit values by vehicle classes on the section of the road M-I-108, Klupe – Teslić (Barići). Vehicle speeds were measured at three different longitudinal gradients ± 3.00%, ± 5.70% and ± 4.06%. It is important to emphasize that speeds on descents and speeds on ascents were measured separately. The speed limit is 50 km / h.

The percentage share of certain vehicle classes in traffic flow that occurs on the observed section is shown in Figure 1. It is important to point out that the BUS category was excluded from further consideration due to small number of buses, insufficient for reliable analysis.

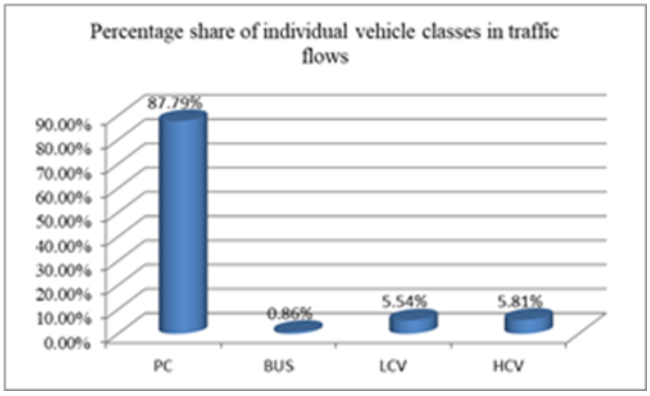
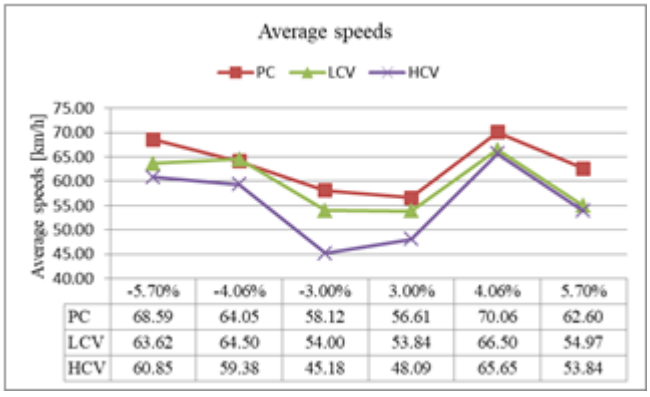


Fig. 1 *Percentage share of individual vehicle classes in traffic flows*

The following figure shows average vehicle speeds where it can be noticed that all vehicle classes at all observed descents and ascents drive at an average speed higher than the limit, except for heavy commercial vehicles which have a slightly lower average speed than limited only at a descent and ascent of 3.00%. The highest average vehicle speeds were recorded on the road segment with a descent of -5.70% and an ascent of + 4.06%.



	-5.70%	-4.06%	-3.00%	3.00%	4.06%	5.70%
PC	68.59	64.05	58.12	56.61	70.06	62.60
LCV	63.62	64.50	54.00	53.84	66.50	54.97
HCV	60.85	59.38	45.18	48.09	65.65	53.84

Fig. 2 *Average vehicle speeds*

The total percentage of drivers exceeding the speed limit on the observed section is 85.78%. Figure 3 shows the speeding classes. Extreme cases where drivers drive over 40 km/h above the limit are rare and it is difficult to appeal to their consciousness, so they are excluded from further consideration.

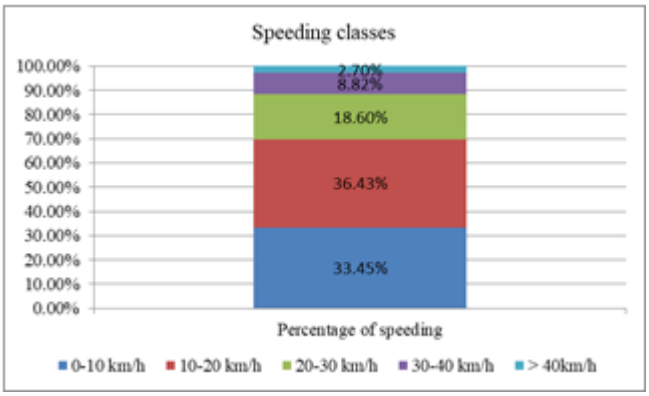


Fig. 3 *Display of speeding classes*

Figure 4 shows a detailed speeding of the considered vehicle classes on all observed descents and ascents of the Klupe – Teslić section according to the speeding classes.

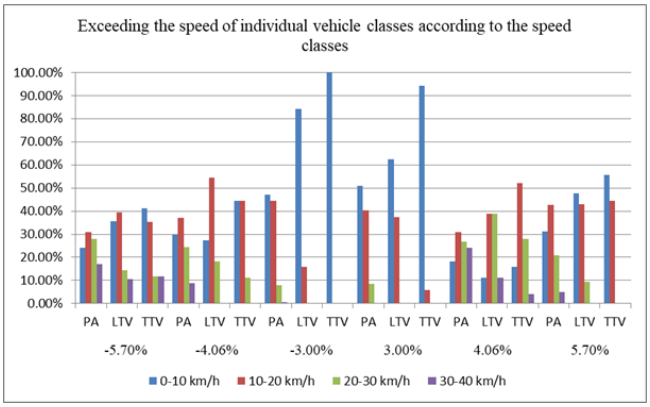


Fig. 4 *Exceeding the speed of individual vehicle classes according to the speed classes on the observed slopes*

Figure 5 clearly shows that only a small percentage of drivers comply with the posted speed limit on all observed slopes, and Figure 6 presents the speeding on the observed cross-sections by speeding classes (speeding up to 10 km/h, 10-20 km/h, 20-30 km/h and 30-40 km/h).

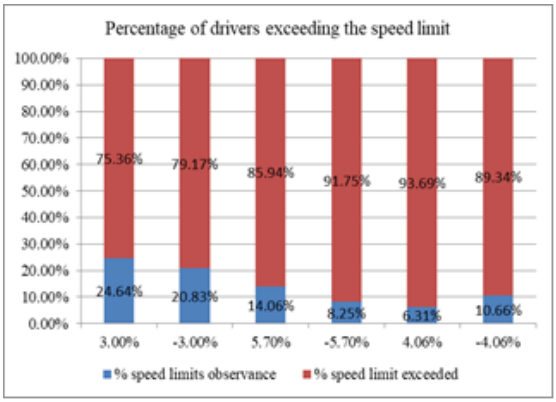
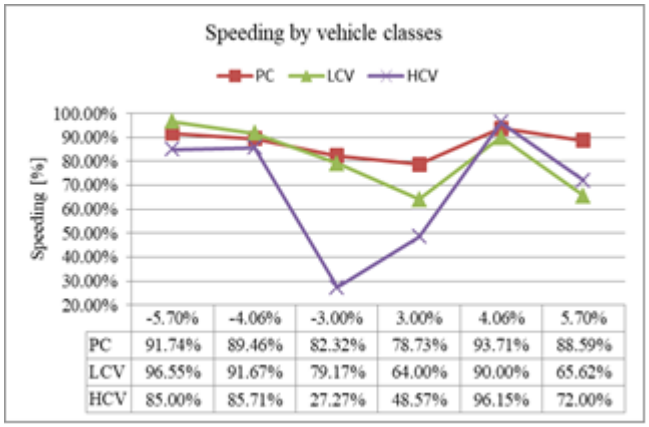


Fig. 5 *Percentage of drivers exceeding the speed limit*

Figure 7 shows the percentage of speeding exceeded by vehicle classes on all observed descents and ascents along the Klupe - Teslić (Barići) section. On the road segment with a slope of 3.00% (both on a descent and on an ascent) and on an ascent of + 5.70%, it was noticed that passenger cars, compared to other vehicle classes, most often exceed the posted speed limit, while in other places there is frequent speeding by passenger cars and a large share in speeding of light and heavy commercial vehicles.



	-5.70%	-4.06%	-3.00%	3.00%	4.06%	5.70%
PC	91.74%	89.46%	82.32%	78.73%	93.71%	88.59%
LCV	96.55%	91.67%	79.17%	64.00%	90.00%	65.62%
HCV	85.00%	85.71%	27.27%	48.57%	96.15%	72.00%

Fig. 7 *Display of speeding by vehicle classes*

The following figure, based on a relative frequency, shows the distribution of passenger cars exceeding the speed limit. The speed value varies, and a precise distribution cannot be defined, especially for commercial vehicle classes. The frequency of any data is the number of occurrences of the data, and a relative frequency is by definition the quotient of an ordinary frequency and the total amount of data. If the variable has a lot of different values, as in this case, and if we want to display the data by a table of frequencies and relative frequencies, it is useful to group the values into classes. It is important to indicate that different classes may not contain the same values. In this case, the classes, i.e. class frequencies are in a range of 2 km/h. By entering the values from the tables created in Microsoft Office Excel into the TableCurve 2D V5.01 statistical program, the following graph was obtained using the Normal (Gaussian) distribution. The software works on a principle of selecting a specific distribution to which the input data best fits.

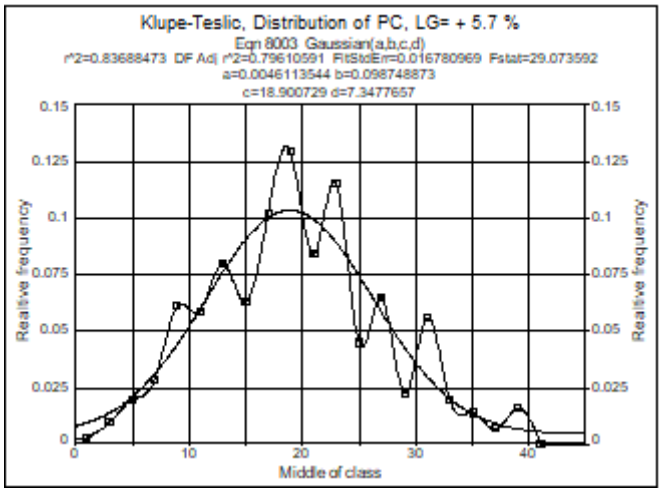
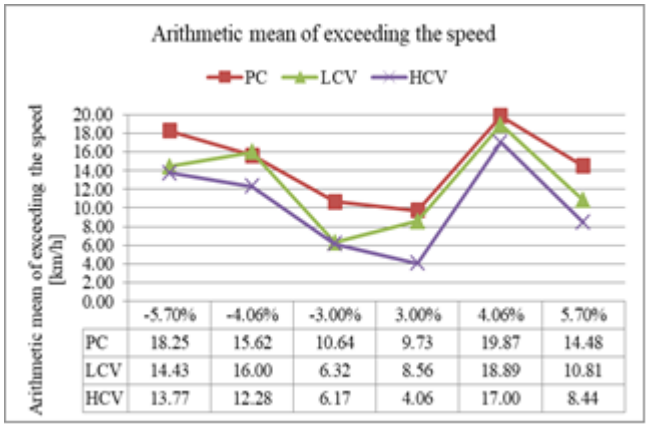


Fig. 8 *Distribution of PC on a grade of + 5.70%*

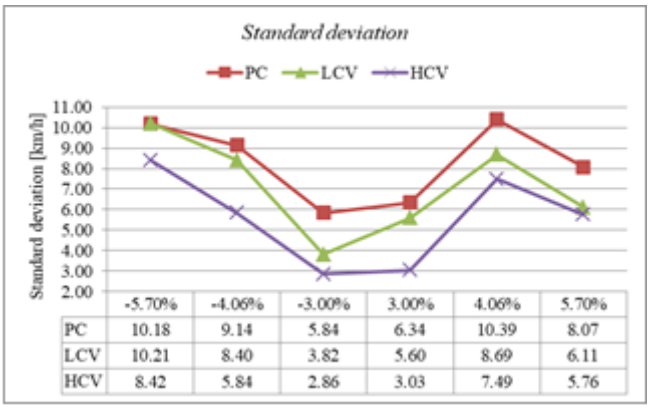
The following figure shows the empirical arithmetic mean of exceeding the limit. It can be noticed that the largest arithmetic mean of speeding was recorded at a descent of -5.70% and an ascent of + 4.06% because these segments are straight and are suitable for reaching higher speeds. Analogously, it is concluded that the lowest values are recorded on the segments where there are curves because drivers have to reduce their driving speed in order not to lose control of vehicles.



	-5.70%	-4.06%	-3.00%	3.00%	4.06%	5.70%
PC	18.25	15.62	10.64	9.73	19.87	14.48
LCV	14.43	16.00	6.32	8.56	18.89	10.81
HCV	13.77	12.28	6.17	4.06	17.00	8.44

Fig. 9 *Empirical arithmetic mean of exceeding the speed*

The standard deviation is an average deviation of the value of a numerical variable from its arithmetic mean. If the standard deviation is small, the arithmetic mean represents the results well. The following figure shows the standard deviation or deviation from the average speeding value. It can be seen that this graph is similar in shape to the previous graph showing the empirical arithmetic mean. It is concluded that the largest deviations are on those cross-sections where the largest average speeding is recorded.



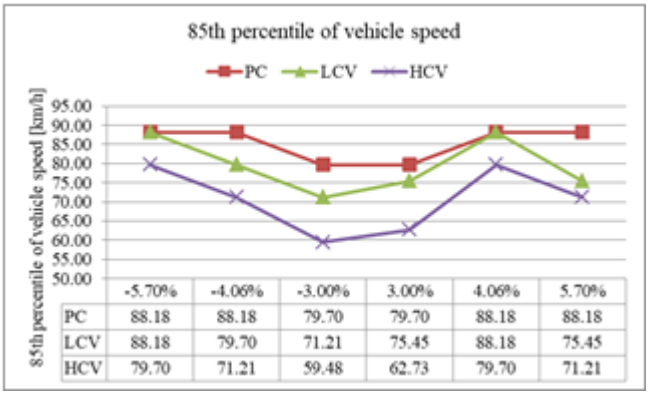
	-5.70%	-4.06%	-3.00%	3.00%	4.06%	5.70%
PC	10.18	9.14	5.84	6.34	10.39	8.07
LCV	10.21	8.40	3.82	5.60	8.69	6.11
HCV	8.42	5.84	2.86	3.03	7.49	5.76

Fig. 10 *Display of standard deviation*

Based on the results presented so far, it is more than clear that the posted speed limit of 50 km/h on the Klupe – Teslić (Barići) section is not credible because drivers encounter the problem of discrepancy between technical and exploitation characteristics of the road and speed limit values.

In case that a speed limit is not credible, one of the two possible ways of solving the problem is chosen: redefining the posted speed limit based on system analysis which means increasing or decreasing existing values or changing

road and environment elements by applying certain design measures in accordance with traffic conditions [15].
The 85th traffic flow speed percentile is an integral part of one of the most commonly used methods for determining speed limits on roads. Namely, it is assumed that most drivers are reasonable and do not want to suffer accidents, but they also want to get to their destination as quickly as possible. Therefore, the speed at which 85.00% of people drive is considered the highest safe speed for the road. For this reason, the 85th percentile was calculated. The 85th percentile speed values were obtained using the TableCurve 2D V5.01 statistical software and are shown in Figure 11.



	-5.70%	-4.06%	-3.00%	3.00%	4.06%	5.70%
PC	88.18	88.18	79.70	79.70	88.18	88.18
LCV	88.18	79.70	71.21	75.45	88.18	75.45
HCV	79.70	71.21	59.48	62.73	79.70	71.21

Fig. 11 *Values of the 85th percentile of vehicle speed in traffic flow*

5 DISCUSSION OF RESEARCH RESULTS

This paper shows that only a small percentage of drivers comply with the posted speed limit on all observed slopes, but the most critical situation is on road segments with an ascent of + 4.06% (where 93.69% of drivers exceed the speed limit) and on a descent of -5.70% (91.75% of drivers exceed the speed limit).
Namely, these road segments are straight, so drivers do not see an objective reason why they would reduce their speed since the road is in very good condition, traffic lanes have quite sufficient width of 3.5 m, and side obstacles are not along the edge of the road, i.e. satisfactory road and traffic conditions prevail, which allow vehicles to move at speeds higher than the limited ones. These findings show the importance of setting speed limits that coincide with the visual appearance of the road because otherwise there is significant speeding. All this indicates that it is necessary to reconsider the validity of the speed limit.
When it comes to the distribution by speeding classes, it can be noticed that on the road segment where the vehicle speed is measured on an ascent and a descent of 3.00% and on an ascent of + 5.70%, there are most of the drivers who reached speeds up to 10 km/h higher than the limit and those driving at speeds 10-20 km/h over the limit. In the remaining cross-sections (at a descent of -5.70% and at an ascent and a descent of 4.06%), most drivers were driving 10-20 km/h and 20-30 km/h over the speed limit.
These results can be justified by the fact that vehicles on the road segment with a slope of 3.00%, as well as on the road segment where the vehicle speed was measured on an ascent of + 5.70%, must drive a little slower due to a reduced radius of horizontal curves and analogously, larger deviations from the speed limit were recorded on the remaining cross-sections where the vehicle speeds were measured since these road sections are straight.
The group of drivers exceeding the limit by 10 km/h belongs to a group that can be preemptively affected, so it should be worked on the application of measures (primarily police control) in order for this group to start to comply with posted limits [3].

If the speeding is observed by vehicle classes, it can be noticed that on the road segment with a slope of 3.00% (both on a descent and on an ascent) and on an ascent of + 5.70%, passenger cars, compared to other vehicle classes, exceed the speed limit with a significant percentage, while in other places, in addition to frequent speeding by passenger cars, there is a large share in the speeding of light and heavy commercial vehicles. As already mentioned, there are curves on the road segment with a slope of 3.00% and on an ascent of + 5.70%, and it is quite understandable that a slightly smaller number of light and heavy commercial vehicles, compared to passenger cars, drive over speed limits on these road segments due to the risk of vehicle overturning.

The presence or absence of a reduction in a radius of curvature is one of the main factors influencing the credibility of the speed limit [16].
Several researchers have shown that changes in traffic flow, changes in headways, as well as changes in speeds can be successfully described using probability distribution laws. In this paper, a relative frequency representing the speeding is distributed mainly according to the Normal (Gaussian) or Log-normal distribution. The normal distribution is the best-known, and the most commonly used distribution function in statistics. It is symmetrical in relation to the arithmetic mean and is bell-shaped.
The log-normal distribution is very close to normal. It is possessed by a variable with a logarithm normally distributed. Normal and log-normal distributions are determined by mean and variance [17].
In many countries, an engineering method, i.e. the concept of adapting the speed limit to actual driving speeds, such as the 85th speed percentile, is used to set speed limits on a particular road section to ensure that the limits are acceptable to most drivers. The speed limit on the observed segments of the Klupe – Teslić (Barići) section is 50 km/h.
Through the results of this research, it has been determined that the posted speed limit is not valid, so the values of the 85th percentile were identified, according to which a speed limit of 80 km/h should be set on the road segment with a slope of 3.00%, and a speed limit of 90km/h should be set on road segments with a slope of 5.70% and 4.06%. It is also possible to design a layout of the road that would result in a more harmonious relationship between the actual operating speed and the posted speed limit. By setting credible limits, the percentage of exceeded speed limits would be lower, thus achieving a smaller dispersion of vehicle speeds in traffic flow, and consequently improving traffic efficiency and safety.
It is important to mention that several countries have lower speed limits for heavy vehicles, which are fully justified by their higher mass and associated risk of causing severe injuries and the longer braking distances they require [12].

6 CONCLUSION

The total percentage of drivers who exceed the speed limit on the observed section of the main two-lane road M-I-108, Klupe – Teslić (Barići), is 85.78%.

On all observed slopes, only a small percentage of drivers comply with the posted speed limit, but the most critical situation is on segments with an ascent of + 4.06% (where even 93.69% od drivers exceed the speed limit) and on a descent of -5.70% (91.75% of drivers exceed the speed limit). These road segments are straight, so drivers do not see an objective reason why they would reduce their speed, i.e. satisfactory road and traffic conditions allow vehicles to move at speeds that are higher than the limits. Thus, it is concluded that the posted speed limit should coincide with the visual appearance of the road because otherwise there is significant speeding.On a road segment with a slope of 3.00% (both on a descent and on an ascent) and on an ascent of +5.70%, it was noticed that passenger cars, compared to other classes of vehicles, exceed the posted speed limit by a large percentage, while on other places in addition to frequent speeding by passenger cars, there is a large share in speeding of light and heavy commercial vehicles. The summary results of this paper indicate dominant unsuitability and the question of the credibility of the posted limits and the need to reconsider the overall speed management concept. If a speed limit is not credible, it is possible to change the posted speed limit or change the elements of the road and the environment. In many countries within the European Union, notably France, Germany and Austria, the 85th speed percentile is used to set speed limits on a given road section to ensure that the limits are acceptable to most drivers. According to this method, a speed limit of 80 km/h should be set on a road segment with a slope of 3%, and a speed limit of 90 km/h should be set on road segments with a slope of 5.7% and 4.06%. By setting credible limits, the percentage of exceeding the speed limit would be lower, which would lead to a smaller dispersion of vehicle speeds, but also a harmonized traffic flow, and consequently it would improve traffic efficiency and safety.

This research in terms of further studies should be expanded to all sections in BiH. It is also necessary to conduct constant credibility monitoring.

ACKNOWLEDGEMENTS

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