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Original scientific paper

A new concept of the operating speed and speed limit credibility analysis

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Abstract – **This paper presents a new concept of the operating speed and speed limit analysis, using analytical models and empirical research. Also, the analysis of operating speeds as a function of different hourly volume classes was conducted. This method represents the basis for improvement of the operating speed models and a tool for analytical determination of the speed limit credibility.**

Keywords – **Speed limit credibility, Operating speed, Speed management, Hourly volume.**

I. INTRODUCTION

Traffic conditions and road geometric characteristics have a considerable impact on the actual vehicle speeds in the traffic flow. In the literature, the actual speed of vehicles is named the operating speed of the traffic flow. This speed is of great significance. The operating speed is one of the basic parameters for describing traffic flow conditions, i.e. it is one of the main criteria for estimating the efficiency (level of service) of a road section. Actual speeds on two-lane roads depend on a large number of factors which are related to drivers, vehicles, road environment, radius of the horizontal curve, curvature rate, longitudinal grade, length of horizontal curves, deflection angles, sight distance, side friction angles and pavement state [1]. The operating speed value is significantly affected by the speed limit value. Speed limits, as one of the key elements of the road management policy, aim to harmonize the speeds in the traffic flow using technical and operational characteristics of the road section and environment, thus minimizing potential risks. However, speed limits are frequently set without appropriate consideration of the basic road and traffic characteristics. This results in exceeding the speed limit and considerable speed dispersion in the traffic flow.

Numerous studies have shown that the increase of speed results in the occurrence of traffic accidents and their consequences [2, 3]. However, the expressed values of speed limit exceedance have a completely opposite effect – they increase the risk of traffic accident occurrence. The reason for this is the (non)credibility of the posted speed limits, i.e. the fact that the speed limits are not in accordance with the characteristics of the road, traffic flow and environment [4, 5]. Drivers would probably comply with the speed limit if they considered it to be realistic and suitable for the road, i.e. reasonable (logical) or “credible” [6, 7]. Otherwise, the driver’s perception of the appropriate speed on a specific road section might not be in accordance with the set speed limit. According to Gardner & Rockwell, drivers tend to rely more on their own estimation regarding the appropriate speed than on the posted speed limit [8].

In addition, the non-compliance with speed limits results in the great dispersion of vehicle speeds in the traffic flow, which has a considerably negative impact on traffic safety. The larger the difference in vehicle speeds in the traffic flow, the greater the number of traffic accidents [1, 9] and severity of traffic accident consequences [10, 11]. In their paper, Garber and Gadiraju attempted to quantify the relationship between the speed dispersion and traffic accident rate [12]. They confirmed that the speed dispersion in the traffic flow was greatly influenced by the difference between the speed limit and design speed. It was determined that the speed dispersion would be the lowest if the posted speed limit was lower than the design speed by 8 to 17 km/h. Outside this range, the increasing difference between the mentioned speeds leads to an increase in the speed dispersion in the traffic flow. It was also determined that drivers tended to increase their driving speed in case of favourable geometric characteristics of the road (regardless of the posted speed limit) and that the rate of traffic accident occurrence did not necessarily rise with the increase in speed, but that it did rise with the increase in the speed dispersion in the traffic flow.

The review of the relevant literature which underlined all problems related to non-credible speed limits showed that a study dealing with this problem should be conducted in order to provide specific conclusions, measures and recommendations.

Therefore, this paper presents a new concept for the operating speed and speed limit analysis by means of analytical models and empirical research applying new technologies. The research was conducted on the representative road sections of the class I state roads in the Republic of Serbia.

The main objective of this paper is to examine the existing and innovative models for calculating the operating speed and carry out a comparative analysis of the obtained results and the actually realized speed values. In this manner, the most favourable model can be defined and it could be applied on all sections of two-lane roads when analyzing the posted speed limit credibility.

II. METHODOLOGY

Following the review of the relevant literature which highlighted all the problems of non-credible speed limits, it was determined that there was a need for conducting adequate research in the Republic of Serbia. Previous intensive research

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on the speed limit credibility in the Republic of Serbia had included all sections of the class I state roads equipped with automatic traffic counters, i.e. as many as 227 sections with approximately 492 million vehicles per year. On the basis of foreign and local experiences in the previous examination of this problem, a methodology was created to analyze the speed limit credibility. The methodology contains several steps:

1. defining the representative sections equipped with automatic traffic counters (ATCs),
2. determining the geometric characteristics of the selected sections,
3. calculating the free-flow speeds of vehicles,
4. analysis of the operating speeds (the actual values and the values obtained in the models),
5. analysis of the speed limit exceedance,
6. systematic analysis.

As seen in the stated steps, the methodology requires the selection of the sections equipped with modern automatic traffic counters (ATC). Namely, the automatic traffic counters operating on the basis of induction loops register not only the traffic volume and flow structure but also the passing speed of each vehicle. Therefore, they provide a considerable sample of the actual operating vehicle speeds on the cross-section of the road sections. On the basis of the geometric characteristics of the selected sections in the ATC zone, the free-flow speed and operating speed obtained in the model should be calculated and compared with the posted speed limits. The conducted analysis can provide the conclusions regarding the credibility of the posted speed limits and the engineering measures which can be applied in order to harmonize the traffic flow speeds and decrease overspeeding.

However, the problems regarding the analysis of the speed limit credibility occur on the sections without automatic traffic counters, i.e. the sections where the actual operating speed cannot be obtained. Examining the speed limit credibility on these sections can be conducted only on the basis of the operating speeds obtained by applying the appropriate models. The literature contains a large number of different approaches for determining this speed. The question is how to define the average operating speed which would be the best representative of the traffic flow conditions. This is the reason why this study examined several most frequently used models on the specific sections with automatic traffic counters in order to find out which one is the most suitable for conducting the analysis of the speed limit credibility in the local conditions.

One of the most used models for calculating this speed is the HCM (Highway Capacity Manual) model, which is also implemented in the software package HCS - Eq. (1) [13]. According to HCM, the operating speed is defined as the average traffic flow speed in the predominant road and traffic conditions.

$$ATS_d = FFS - 0{,}00776 * (v_{d,\ ATS} + v_{o,\ ATS}) - f_{np,ATS} \quad (1)$$

Where:
ATS_d – average travel speed in the analysis direction (mi/h) – Operating speed;
FFS – free-flow speed (mi/h);
$v_{d,\ ATS}$ – demand flow rate in the analysis direction (pc/h);
$v_{o,\ ATS}$ – demand flow rate in the opposing direction (pc/h);
$f_{np,ATS}$ – the adjustment factor for the percentage of no-passing zones in the analysis direction.

Local studies define the operating speed as the average speed of the traffic flow in normal conditions, i.e. the conditions in which traffic participants distract each other [14]. This definition makes this speed representative for the use in the analysis of the posted speed limit credibility. The linear model for calculating the operating speed Vo - Eq. (2), which is the most frequently used method in the local practice, considers only one value of the design hourly volume (for example, the values corresponding to the 30th or 200th hour), while disregarding other hours in a year which are characterized by significantly lower levels of traffic volume.

$$V_{e_i} = \left[V_{Sl_i} - \frac{q_m}{C} \cdot (V_{Sl_i} - V_C)\right] \cdot \left[(1 - R) + \frac{R \cdot P}{100}\right] \quad (2)$$

Where:
i – vehicle category;
V_{Sl_i} – free-flow speed (km/h);
q_m – design hourly volume (veh/h);
C – capacity (veh/h);
V_C – speed at capacity (km/h);
R – the adjustment factor for passing visibility
P – percent of the allowed passing zone

This can result in a series of wrong strategic decisions in the process of evaluating and creating road project designs, as well as estimating the credibility of the posted speed limits. The only way to present the traffic flow conditions more realistically is to include the weighted values of the hourly volume classes as a function of the number of hours into the process of calculating operating speeds.

Using the current level of knowledge regarding the traffic flow theory and engineering economics, new methods have been developed for determining the actual values of the design volume and operating speeds, based on the analysis of volume per classes. Previous analyses, based on the recommended number of hours per class provided by the HDM4 model (C5-87,6; C4-350,4; C3-613,2; C2-2978,4; C1-4754,4), resulted in low sensitivity, i.e. a small change of average volume values, particularly for the two last classes (C4 and C5). Consequently, the classes were redefined (C5-50; C4-200; C3-1000; C2-4000; C1-3534) [15]. Therefore, this study also calculated the operating speed values as a function of design hourly volumes on the observed sections by calibrating the local model according to the mentioned volume classes.

III. RESULTS AND DISCUSSION

In order to test the stated models for calculating the operating speeds, the speed credibility analysis was conducted on the sections equipped with automatic traffic counters. The comparative analysis includes the comparison of the data on the actual speed values and calculated operating speed values, and their comparison with the speed limits. In this manner it is possible to make initial conclusions regarding the credibility of the posted speed limits on the class IB roads, i.e. on the sections observed in the study, and determine which model is the most applicable in the local conditions.

On the basis of the mentioned previous research on the speed limit credibility conducted on 227 sections, characteristic representative sections were selected. For the comparative analysis of all the stated results, the sections of class IB with different geometriccharacteristics were selected. Namely, the following sections were selected as the subject of the study: five sections without critical road elements (WCRE), three sections with the critical radius of the horizontal curve (Rmin), two sections with the critical longitudinal grade (Grade) and two sections with the combined impact of critical radius and longitudinal grades (Rmin+Grade). The sections without critical road elements were the sections of the so-called *Ibarska Magistrala*, i.e. the sections of one of the most significant routes in the Republic of Serbia. The selected sections have different average annual daily traffic (AADT) and flow structure. They were selected in order to examine the impact of these traffic flow characteristics on various models of operating speeds. When it comes to the sections with the critical minimal radius of the horizontal curve or longitudinal grade, the examples with the most critical geometric characteristics were selected. It should be mentioned that there is a small number of such sections in the class I network since the traffic counting methodology does not involve posting automatic traffic counters on critical segments. The results of the conducted analysis are presented in Figure 1 and Table I.

Comparing the actual operating speed from the ATCs and the posted speed limits, it was determined that the highest overspeeding was recorded on the sections with low speed limits (50 km/h). These are the rural sections where ATCs are posted at the very beginning of the residential zones where technical and operational road characteristics enable driving at a high speed. Consequently, the greatest speed limit exceedance was recorded on the section Meljak-Stepojevac (ATC 1244) amounting to as much as 97%, as well as on the section Ćelije-Županjac amounting to 96%. On the other hand, the sections with poorer geometriccharacteristics (Rmin, critical longitudinal grade or the combined impact of these two characteristics) included the sections where the realized actual operating speeds were lower than the speed limits. This is the case on the section Bečej-Novi Bečej (ATC 2036) which has the minimum radius of the horizontal curve of 129m in the ATC zone, which is why only 4% of drivers exceed the speed limit, while the actual operating speed is lower than the speed limit by 31%. Also, the section which has a potential for the possible reduction of the speed limit due to poor geometriccharacteristics (the minimum radius of 57m and longitudinal grade of 5.9% in the length of 911m) is the section Dub-Dubci (ATC 1043). On this section, 99.7% of drivers were registered to comply with the 80 km/h speed limit, while the actual operating speed was by 39% lower than the speed limit.

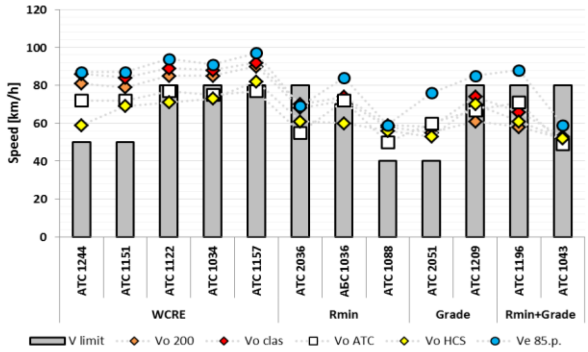

Fig. 1. The comparative analysis of speeds

The matching of the operating speeds obtained in the models with the actual operating speed from ATCs is presented in Table I.

TABLE I
THE PERCENTAGE OF DIVERGENCE OF THE SPEEDS OBTAINED IN THE MODEL AND THE ACTUAL SPEEDS FROM ATCS

Percentage of divergence (%)	of Vo_{HCS} from Vo_{ATC}	of Vo_{200} from Ve_{ATC}	of Vo_{class} from Ve_{ATC}
ATC 1244	0.18	-0.13	-0.19
ATC 1151	0.04	-0.10	-0.17
ATC 1122	0.08	-0.10	-0.16
ATC 1034	0.03	-0.13	-0.17
ATC 1157	-0.06	-0.17	-0.19
ATC 2036	-0.11	-0.24	-0.27
АБС 1036	0.17	0.00	-0.03
ATC 1088	-0.12	-0.16	-0.18
ATC 2051	0.12	0.08	0.03
ATC 1209	-0.04	0.09	-0.10
ATC 1196	0.14	0.18	0.07
ATC 1043	-0.06	-0.06	-0.08
|average|	**0.10**	**0.12**	**0.14**

Generally, the obtained results show that the HCM model offers the operating speed values which are the most similar to the actually realized speeds. The absolute percentage of divergence of the speeds calculated by means of the HCM model and the actual speeds amounts to only 10%. On the other hand, the absolute percentage of divergence of the operating speeds obtained in the local and calibrated local models from the actual speeds amounts to 12% and 14%, respectively. When the observed sections are separately studied in terms of the existence of critical road elements, the results are as follows. On the roads without critical road elements where the operating speed is based on the road cross section, the speeds obtained in the HCM model showed a significantly greater matching with the actual speeds (8% of divergence) than the speeds obtained by the application of the two other models (divergence of 13% and 18% in the local and calibrated local model, respectively). Different AADT values (from 14465 veh/day to 5742 veh/day) did not have a significant impact on the obtained values. Their impact is only observed in the fact that the difference between the classic and calibrated local model slightly decreases with the reduction of the values. The traffic flow structure also insignificantly affects the obtained results in the model. On the contrary, on the sections with the critical minimum radius of horizontal curves and critical longitudinal grades, the HCM model and the calibrated local model have the operating speed values which are the most similar to the actual speeds (divergence of 11%), while somewhat poorer matching was recorded for the speeds obtained in the local model (divergence of 12%).

IV. CONCLUSION

Speed limits represent a significant element of the speed management policy. The analysis of the speed limit credibility on the basis of the existing foreign and local experiences was limited to the sections equipped with ATCs. The main contribution of this paper is the improvement of the model for the operating speed analysis, comparative testing of these speeds and definition of the most suitable model for the analytical determination of the speed limit credibility on all two-lane sections of state roads.

The analysis was conducted on 12 representative sections of the class IB state roads in the Republic of Serbia, which contain different road geometric and traffic flow characteristics. The study tested the two most frequently used models for calculating operating speeds – the HCM model and local model, as well as the calibrated local model as a function of hourly volume classes.

On the basis of the obtained results it can be concluded that the HCM model for calculating operating speeds has the best matching with the actual operating speeds obtained from the ATCs. This was expected having in mind this model's complexity (the largest number of influential factors) and constant improvements. When it comes to the local and calibrated local model as a function of the hourly volume classes, it can be concluded that the traditional local model is more adequate for the application on the sections without critical technical and operational characteristics, while the calibrated model offers slightly better results on the sections with critical radius of horizontal curves and longitudinal grades. Generally speaking, the HCM model is universal and applicable on the largest number of sections, while the calibrated local model as a function of the hourly design classes can be applied on the sections with exceptionally poor geometriccharacteristics.

The limitation of the paper is the relatively small number of studied sections (the total of 12), which should be increased in the future research. This primarily refers to the sections with critical technical and operational characteristics (Rmin, longitudinal grade, carriageway width, etc.) which are equipped with ATCs and which are not highly present in the class I state road network. In addition, future research should conduct the analysis of using hourly volumes per class in the HCM model, i.e. examine the matching of thus obtained operating speed values with the actual speed values from ATCs. This is the only manner to reach the final argumentative conclusion regarding the most suitable model for the calculation of operating speeds while analyzing the speed limit credibility.

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