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Estimating percent-time-spent-following on two-lane rural roads

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Preliminary report

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Two-lane rural roads in Bosnia and Herzegovina take up the highest percentage of the national road network and thus carry almost the entire heavy traffic. That is why long platoons are often formed on such roads, vehicle speed is low, and traffic density is high. In order to improve the quality of traffic, it is necessary to determine the level of service for the existing situation and for alternatives involving reconstruction of critical elements along this road network. The percent-time-spent-following is studied in this paper as it is an appropriate measure for determining efficiency of two-lane rural roads.

Key words:

percent-time-spent-following, two-lane roads, headway

Prethodno priopćenje

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Istraživanje postotka vremena provedenog u koloni na dvotračnim izvangradskim cestama

Dvotračne izvangradske ceste u Bosni i Hercegovini čine najveći postotak cestovne mreže pa preuzimaju gotovo cjelokupan teretni promet. Zbog toga se na njima često stvaraju kolone, brzine vozila se smanjuju i gustoća prometa raste. Za poboljšanje kvalitete odvijanja prometa potrebno je utvrditi razinu usluge za postojeće stanje te za alternativne mogućnosti rekonstrukcije kritičnih elemenata cestovne mreže. U radu se istraživao postotak vremena provedenog u koloni kao primjerena mjera za određivanje efikasnosti izvangradskih dvotračnih cesta.

Ključne riječi:

postotak vremena provedenog u koloni, dvotračne ceste, vrijeme slijeda

Vorherige Mitteilung

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Untersuchung des Prozentsatzes der Zeit, die man auf zweispurigen Landstrassen im Stau verbringt

Zweispurige Straßen außerhalb der Stadt machen in Bosnien und Herzegowina den größten Anteil am Straßennetz aus und übernehmen fast den gesamten Güterverkehr. Deswegen kommt es auf diesen häufig zu Staus, die Geschwindigkeit der Fahrzeuge wird verringert und die Verkehrsdichte nimmt zu. Um die Qualität des Verkehrsflusses zu verbessern, ist es notwendig, das Niveau der Leistung für die bestehende Situation sowie für die alternativen Möglichkeiten der Rekonstruktion der kritischen Elemente des Straßennetzes festzustellen. In der Abhandlung wird der Prozentsatz der Zeit untersucht, die man im Stau verbringt, als angemessene Maßnahme für die Festlegung der Effizienz der zweispurigen Straßen außerhalb der Stadt.

Schlüsselwörter:

Prozentsatz der Zeit, die im Stau verbracht wird, zweispurige Straße, Zeitsequenz

1. Introduction

Rural two-lane highways make up the highest percentage of highway network in many countries, and thus also in Bosnia and Herzegovina (B&H). Traffic volume (AADT) on highways in B&H varies from several dozens of vehicles to more than 12,000 vehicles per day, and the design speed varies from 40 to 80 km/h. Due to poor development of other forms of transport infrastructure, the entire heavy traffic is operated via this network. For the above mentioned reasons, vehicle speeds are quite limited compared to the assumed for the particular highway categories. Because of the hilly and mountainous configuration of terrain the opportunities for passing are limited, which causes frequent traffic jams. Under such circumstances, and especially at high traffic volumes, long platoons are formed, driving speed is reduced, and traffic density is increased. This also causes dangerous maneuvers such as passing at points where such actions are not allowed, which often leads to traffic accidents. Such actions, implying crossing into the opposing lane, are the frequent cause of traffic accidents with grave consequences. To select the way to improve the network (longer passing zones, additional lanes, etc.) it is necessary to determine the quality of traffic operation under current circumstances, and the traffic improvement possibilities.

According to the Highway Capacity Manual HCM [1, 2], the level of service on rural two-lane highways is defined by means of two measures of performance, namely the average travel speed (ATS) and percent time spent following (PTSF). Considering that the maximum speed limit on two-lane highways in B&H is 80 km/h, it may be said that HCM assumes relatively high free flow speed values (70-110 km/h). As the ATS values of less than 64.36 km/h (40 mi/h) results in the level of service E for Class I highways, the ATS can hardly be applied as a criterion under local conditions. That is why the PTSF is considered in this paper and the ATS is not.

PTSF field research/surveys conducted on a national road in B&H in the spring and summer of 2017 are presented in the paper (the initial research conducted in spring are published in [3]).

This paper starts with a brief overview of recent PTSF research conducted worldwide. Field measurements are then described, and research results are presented. This is followed by comparison of PTSF values with the results obtained by some models presented in the following section. As the use of the HCM methodology is recommended in B&H and in the Republic of Croatia, the HCM methodology assumptions are analysed trough comparison with results obtained by field measurements of PTSF values. Based on results obtained by analysis, disadvantages of the use of HCM methodology in the calculation of PTSF are presented.

2. Brief overview of recent PTSF research

A brief overview of recent PTSF research, with an appropriate critical commentary, is given in this section. Due to PTSF parameter, the HCM methodology has been the subject of criticism from the very beginning of its implementation [2]. The reasons behind this criticism lie in much higher PTSF values obtained by calculation using HCM, as compared to on site measurement results [4-14], and the way PTSF was measured via the constant headway. It was assumed that the constant headway does not take into account behaviour of drivers and their desired headways (HCM defines a 3 s headway as a limit for defining the PTSF). Other approaches to PTSF definition have also been proposed [9-14]. Finally, some completely new measures of performance for LOS determination have been reported [15-18].

The methods that use the PTSF as the measure of performance for LOS are listed and analysed below. They involve two approaches. The first approach is aimed at a more thorough definition of the PTSF through detailed analyses of the traffic flow operation parameters such as the probability of platoon formation, speed of various vehicle categories, etc. The second approach involves preparation of PTSF models using limit headway values of 3 s, either by introducing completely new parameters and principles, or by making adjustments to comply with local conditions.

Luttinen (2001) [4, 5] conducted his studies in Finland and established that the on-site measured PTSF values were considerably lower compared to those obtained by calculation using the HCM. He made a critical commentary on the distribution of traffic flows by direction, and on the insensibility of model to speed limits on analysed sections. He also prepared two PTSF calculation models for speed limits of 80 and 100 km/h, respectively. The model proposed by Luttinen [4] for the speed limit of 80 km/h involves the following parameters: directional flow rates, percent of no passing, and influence of shoulder width.

Dixon et al. (2002) [6], Harwood et al. (2003) [7], and Moreno et al. (2014) [8], also report that higher PTSF values were obtained by calculation according to the HCM compared to on site measurements.

Al-Kaisy and Durbin (2007) [9] defined the PTSF by new approaches that involved the probabilistic method and the average weight method. The probabilistic method is based on two variables that are used for determining the percent of followers (P_F): probability that the vehicle is a part of the platoon (P_p) and probability that the vehicle speed is lower than the desired speed (P_i). The average weight method is based on average speeds and average desired speeds of individual vehicle classes. The probabilistic method provided better results compared to the average weight method.

In their research conducted in Israel, Polus and Cohen (2009) [11] linked theoretical and empirical approaches for the determination of LOS. The emphasis was on the analysis of platoons and on the position of vehicles within the platoon. New parameters in the PTSF analysis were an average number of headways between platoons, and an average number of headways within a platoon. They also recommended new ranges of PTSF values for individual LOS values.

In their studies conducted in India, Penmetsa et al. (2015) [13] analysed the number of followers (NF) using the limit headway value of 2.6 s (unlike 3 s used by HCM). The NF parameter offers reliable results, but fails to sufficiently describe traffic flow conditions. The NF can be the same for two roads of similar volume, but greater congestions will be observed on the road with smaller capacity. That is why they introduced a new performance measure: number of followers as a proportion of capacity (NFPC).

Moreno et al. (2016) [14] analysed on Spanish roads the passing influence on the ATS and PTSF. Both ATS and PTSF (just like in the HCM) are defined as a sum of basic influence and influence of no passing zone, with an additional parameter that represents the passing zone length. They proposed that an influence of length of individual passing zones be defined in the next edition of the HCM, together with the total percentage of no passing zone.

3. PTSF study on rural two-lane highways in B&H

The methodology of field research conducted on rural two-lane highways in Herzegovina is presented in this section. The two-lane network is divided into local roads, regional roads, and national roads. According to road classification elements (road function, length, traffic volume, and speed), national roads are the most significant roads in the two-lane road network. Although the design speed is most often 80 km/h on these roads, and although route elements are more homogeneous compared to the other two road classes, lower speeds are often registered at some sections lying in difficult terrain. Thus the average driving speeds on such roads are lower – due to platoons that form after slow vehicles - compared to the values that are used in the HCM methodology for defining the level of service. Consequently, the research is concentrated on the calculation of PTSF, which has been adopted as a measure of performance.

3.1. Selected sections and survey sites

A section of the M17 highway, representing the European road E73, was selected as the representative section for studying traffic conditions on national roads in Herzegovina. This section was selected as it has a relatively good geometry and its traffic characteristics are the closest to the HCM classification, which is why it is considered to be well fitted for observing disadvantages of the HCM methodology.

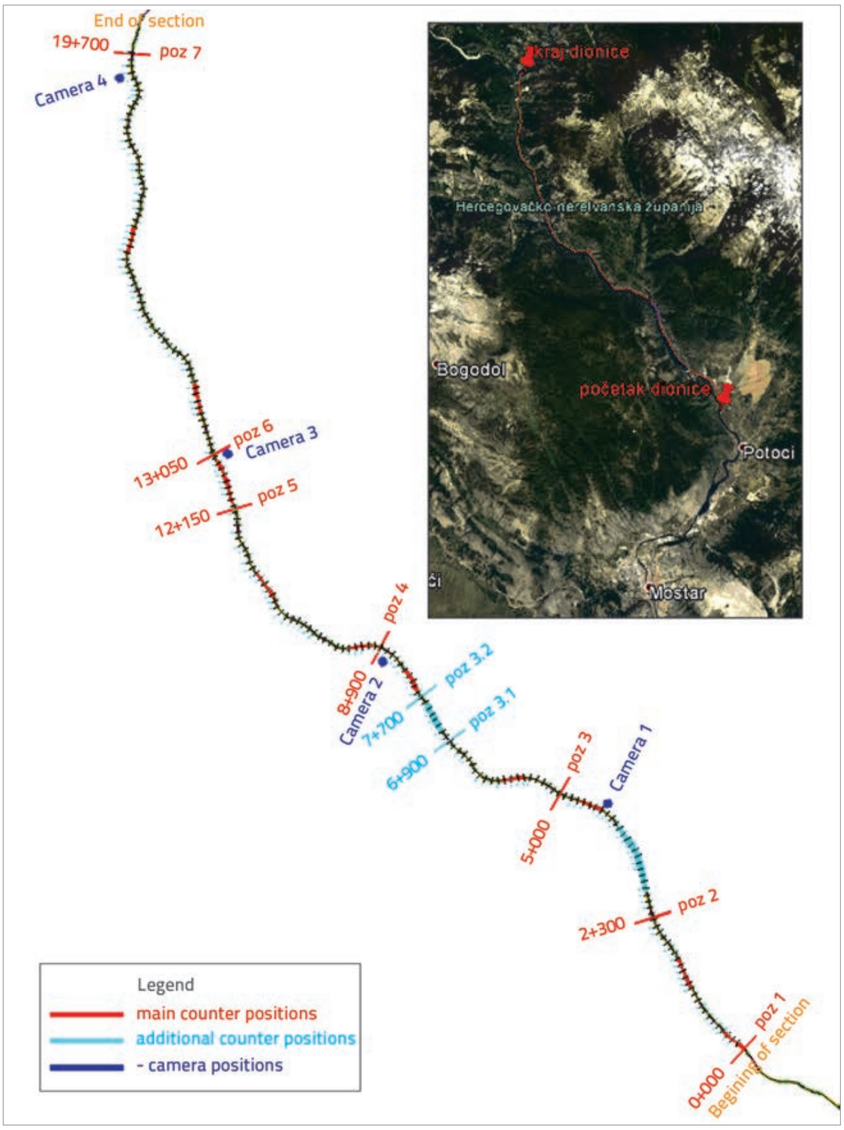

Figure 1. Analysed section Salakovac - Grabovica on the national road M 17

Such interregional sections enable a wide dispersion of driver and vehicle characteristics, and hence the local influence is reduced. The analysis was carried out at the Salakovac – Grabovica section (Figure 1), which is situated between Mostar and Jablanica. The traffic volume of this section (AADT of about 7000 vehicles/day and SADT of about 10,000 vehicles/day) is considerable by B&H standards.

The start of the analysed section (in Salakovac) is situated about 13 km away from the centre of the the city of Mostar. The section is approximately 20 km long and its end point is in Grabovica. Considering the uniformity of its geometry and traffic volume, the section can be considered homogeneous. The influence of access points of local roads is negligible because of very low traffic flow and the existence of left turn lanes on the main road. Main characteristics of the analysed section Salakovac – Grabovica (Figure 1) are:

- section length: 19700 m
- 65 horizontal curves, minimum radius R_{min} = 230 m (average value: 460.35 m, variance 68064.16), average travel speed observed during the study: V = 83.60 km/h
- longitudinal grades < 3 %, except for 3 short zones each less than 300 m in length
- curvature parameter: 71.44 °/km
- 13 passing zones, two zones 1100 m and 700 m in length, respectively, and 11 zones 400 – 450 m in length
- total percentage of passing zones: 30 % (70 % of no-passing zones).

3.2. Survey methodology

Surveys were for the most part conducted in spring and summer (April – August) as that is the time of the year when traffic is more intense (especially in July and August due to tourist season). Surveys were conducted during approximately four weeks (on two or three occasions) at each of the seven main cross sections. The analyses were conducted from 6 a.m. to 10 p.m. because the traffic is negligible in the remaining hours of the day. Fifteen-minute volumes (converted to hourly volumes) were analysed and so, after elimination of extreme values, more than 1300 hourly volumes were obtained. Due to problems with operation of counters at cross sections 4 and 7, this figure was somewhat lower (800 hours). A zone 450 m in length, situated between cross sections 3 and 4 (cross sections 3.1 and 3.2) were also surveyed for ten days (about 450 hourly volumes).
The travel speed and headway were determined at the selected cross sections using portable counter MetroCount 5600. The following information was obtained during the survey: number of vehicles, vehicle class, travel speed, and time of passage of each vehicle by direction of travel. This information was used to accurately define the number of vehicle in the platoon and the PTSF value.
The information on the time of passage of each vehicle by direction of travel (at each cross section) was used to determine the headway and traffic volume in the analysed direction and in the opposite direction. It is considered that a vehicle is in platoon if the headway between vehicles is less than 3 seconds. The ratio of the number of vehicles in platoon to the total number of vehicles is the PTSF in the direction analysed.
Video camera survey was conducted in parallel to the above activities so as to check operation of counters and to obtain an additional insight into operation of traffic (positions in Figure 1).

3.3. Survey results

Several existing models were analysed to determine functional dependence of the PTSF on traffic volume: exponential model variations [4, 5, 11] and multiple regression logarithmic model (as in Spain [14]). The best adjustment to field measurements was exhibited by the multiple regression logarithmic model whose general form is:

$$PTSF = a \cdot \ln(V_d) + b \cdot V_0 + c \tag{1}$$

where:
V_d - traffic flow rate in the analysed direction
V_o - traffic flow rate in the opposite direction
a, b, c - parameters of the multiple regression model

In addition to traffic volumes V_d and V_o, the initial analysis also included the influence of trucks as a third independent variable of the incremental regression model. However, it proved to be negligible (t test revealed the p value of > 5 % in all cross sections) and so it was excluded from further analysis.

The PTSF model equations were obtained for each of the seven cross sections, separately for both directions of travel (coefficient of determination $R^2 > 0.7$ for all cross sections). The results obtained on 7 measurement points for the Salakovac – Grabovica direction are shown in Diagram 1.
The PTSF of the existing section was calculated based on model equations (cf. Diagram 1) by first calculating the PTSF value of each segment that is defined as the average PTSF of neighbouring sections. Then these average values are multiplied with the length of individual segments (difference in chainage, cf. Figure 1), and their sum is divided by the length of the analysed section. This means tha the PTSF of the section is obtained by means of the following expression:

$$PTSF_{section} = \frac{\sum_{i=1}^{6} L_{i,i+1} \cdot (PTSF_i + PTSF_{i+1})/2}{L_{section}} \tag{2}$$

where
$L_{i,i+1}$ - length of segment between cross section i and cross section i+1 [km]
$PTSF_i$ - PTSF value in the cross section i (at the beginning of the segment) [%]
$PTSF_{i+1}$ - PTSF value in the cross section i+1 (at the end of the segment) [%]
$L_{section}$ - length of the entire section [km].

Thus the following expression is obtained for the PTSF value of the section in the Salakovac – Grabovica direction:

$$PTSF_{section} = 20{,}316 \cdot \ln(V_d) + 0{,}006 \cdot V_0 - 65{,}456 \tag{3}$$

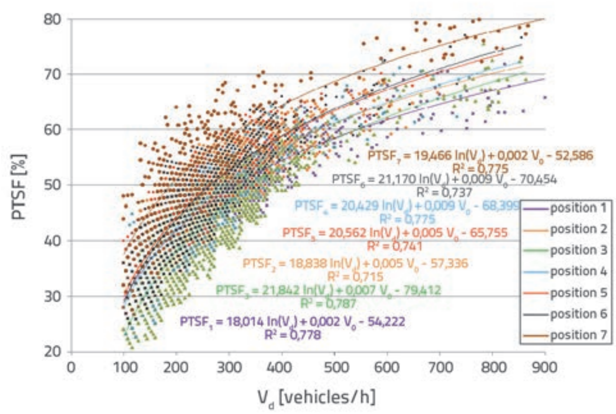

Figure 2. Results obtained at 7 measurement points, direction: Salakovac – Grabovica

4. Comparison of results with HCM methodology and other models

The PTSF values were obtained based on field results for various traffic volumes in the analysed direction and in the opposite direction, for cross sections specified and for the entire section (for both directions of travel).

Table 1. PTSF according to survey results, HCM 2010 and other models (70 NPZ, distr. 50/50)

$V_d = V_o$	HCM 2010	Luttinen, 2001	Al-Kaisy & Durbin, 2008	Polus & Cohen, 2009	Moreno et al., 2014	Field survey, 2017
200	52.80	33.01	35.97	18.26	34.87	43.41
300	60.20	43.65	42.55	26.10	44.78	52.26
400	64.80	52.40	49.13	33.18	51.81	58.72
500	69.90	59.62	55.72	39.59	57.26	63.86
600	74.20	66.07	62.30	45.38	61.71	68.18
700	77.90	71.03	68.88	50.62	65.48	71.92

In addition, calculations were made according to HCM 2010 and some other models for the traffic volume and percentage of no-passing zones (70 %) similar to the values observed for the analysed section. The results are shown in Table 1 and Figure 2. It can be seen from the mentioned table and diagram that some differences exist between the results obtained by field surveys and calculations according to HCM 2010 and other models analysed. HCM offers higher PTSF values for all traffic volumes, while other models analysed provide lower values compared to field surveys.

An increase in traffic volume generates an increase in passing demand, while at the same time the passing capacity decreases. The key change in the quality of operation of traffic flows occurs when the passing capacity decreases considerably. Consequently, the results presented show the expected maximum difference between the measured PTSF values and those determined according to HCM and other mentioned models for lower volumes (from 200 to 400 vehicles/day). For higher volumes, the difference between the modelled and measured PTSF values reduces, as there are no opportunities for passing.

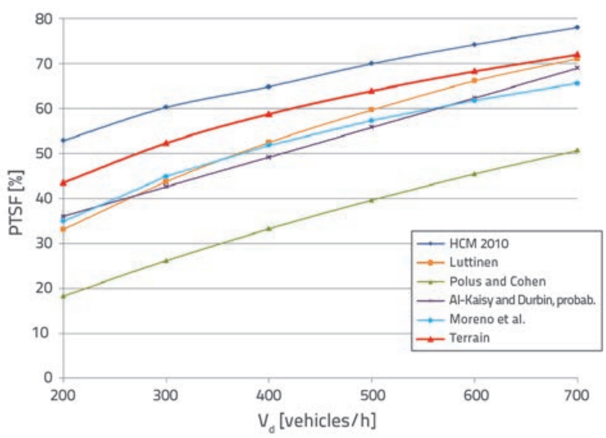

Figure 3. PTSF according to survey results and other models (70 NPZ, distribution 50/50)

4.1. Disadvantages of HCM and other methodologies

As mentioned earlier, the use of HCM methodology is recommended in B&H and Republic of Croatia for determining the level of service in highway traffic, and so this study focuses on its deficiencies.

It can be seen from results presented in Table 1 and Diagram 2 that other models also present differences in PTSF values when compared to field survey results. The model presented by Polus and Cohen [11] provides much lower values when compared to all other models, and the reason for this lies in different approaches to analysis (mentioned analysis of traffic platoons) and different PTSF ranges (compared to HCM) for individual levels of service. The remaining three models analysed also provide lower values compared to those obtained during field surveys. Parameters used in Spanish model presented by Moreno et al. [8] are: total traffic volume and analysed traffic flow volume. These parameters were obtained by regression analysis of data measured during on-site surveys. The Luttinen model for the speed of 80 km/h [4] is characterized by small PTSF sensibility at high percentage of no-passing zones (just like in the case of HCM). The model defined by Al-Kaisy and Durbin [9] reveals high sensitivity to NPZs and trucks, which is not in agreement with field data. It would be difficult to apply these models in B&H because of a specific approach applied in model development and due to parameters used in these models.

Considering the mentioned, and the recommendation for using HCM methodology in B&H, the influences of individual parameters included in HCM methodology on the quality of PTSF prediction in local conditions in chapter 4.2.

4.2. Influences of individual parameters included in HCM methodology on the quality of PTSF prediction

4.2.1. Calculation of PTSF via BPTSF

The BPTSF is an "ideal" section in which passing is possible along the entire length of the section (100 % PZ). At most sections of the rural two-lane network in B&H, passing is possible on 25-30 % of the section, and in many cases this is reduced to approximately 15 % of the section. For that reason, the use of BPTSF as initial parameter is not appropriate for local conditions, as field measurements would be quite difficult. A simpler approach would be to start from calculation of maximum PTSF as related to a section where there are no opportunities for passing (which can easily be measured) and to reduce this value depending on the presence and length of passing zones. This is contrary to HCM approach (which starts from ideal conditions and continues toward prevailing conditions) but, in this way, the PTSF value would be determined more accurately and hence the "correction factors" would also be more accurate (coefficients of influence of passing zones would be much lower compared to the case with no-passing zones f_{np}). As it is very difficult to conduct on site measurements of f_{np}, and as in calculations it is often higher value than BPTSF, the HCM model is considered "unstable" for use in local B&H conditions.

4.2.2. Speed distribution and proportion of trucks in traffic flow

In the HCM methodology, speed has small role in calculation of the PTSF itself, and sensitivity to proportion of trucks (%HV) is very small. A negligible influence of trucks was also obtained by field surveys as conducted in the scope of some earlier research [4, 5]. On the other hand, the speed has a much greater influence on the PTSF because the design speed defines operation of the traffic flow, and differences can be noted on roads where this speed is for instance 100 km/h and 80 km/h [4, 5]. Another significant point is speed distribution, and especially distribution of desired speeds, as they define vehicle interaction and keeping vehicles in a platoon. As this study was conducted on national roads, it relates to the speeds of 80 km/h.

4.2.3. Influence of opposing traffic on PTSF of analysed flow

The influence of the opposing traffic volume (V_o) results in the difference between PTSF values calculated according to HCM 2010 and the values obtained by field measurements (diagrams 3 and 4). According to HCM 2010, the PTSF value of the analysed flow (V_d) decreases with an increase in the opposing traffic volume V_o (which is not logical) for the opposing traffic volume of less than 300 vehicles/hour (Figure 4). The HCM 2010 results in the change of the PTSF in the analysed direction for the case without passing (100 % NPZ), which is not logical as the opposing traffic exerts no influence on the traffic flow in the analysed direction.

Field survey results point to an increase in PTSF with an increase in the opposing traffic volume V_o, which is in accordance with

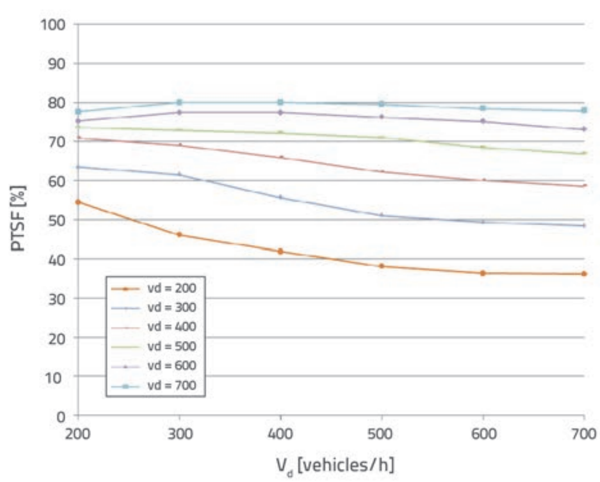

Figure 4. Dependence of PTSF on opposing traffic according to HCM 2010 for 70% NPZ

expectations. Diagram 4 points to an interdependence between the analysed traffic volume V_d and the opposing traffic volume V_o on the section for direction 1 (Salakovac – Grabovica).

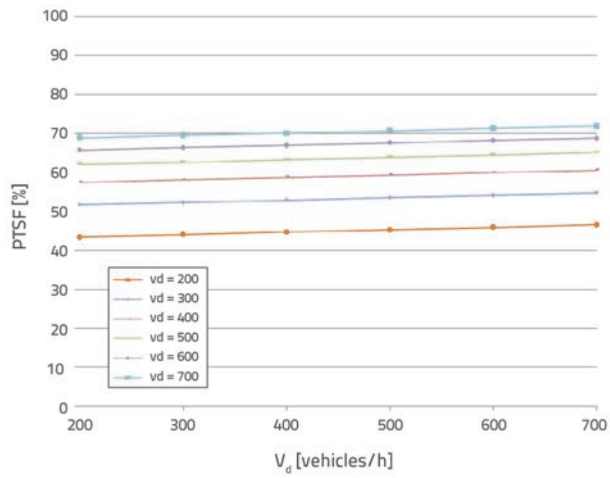

Figure 5. Dependence of PTSF on opposing traffic according to survey results (direction: Salakovac – Grabovica)

4.2.4. Influence of No-Passing zones on PTSF

In the calculation of PTSF, the HCM 2010 takes into account the percentage of no-passing zones (NPZ) without considering their number and length. In addition, differences in values are very small for the NPZ of 60-100 % (Figure 6).

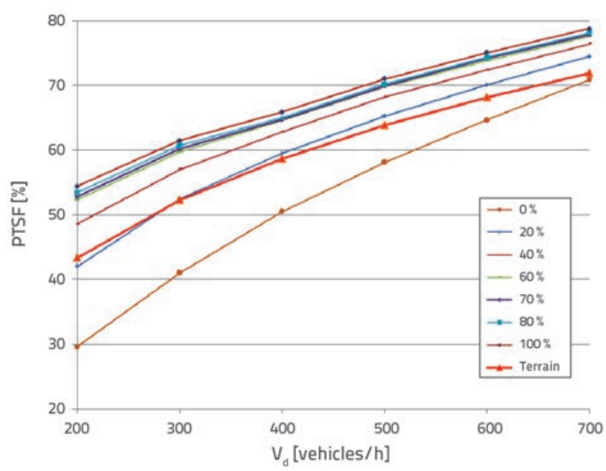

Figure 6. PTSF according to HCM 2010, dependent on NPZ, for distribution by direction: 50/50

Most highways in B&H are characterized by 70 to 100 % of NPZs, which poses a considerable problem for the analysis according to HCM methodology. This results in negligible difference in PTSF values between sections without passing (100 % NPZ) and sections such as the one under study (70 % of NPZs), which does not correspond to the presented terrain values, especially for small road volumes that enable a greater number of passing actions (Figures 7 and 8).

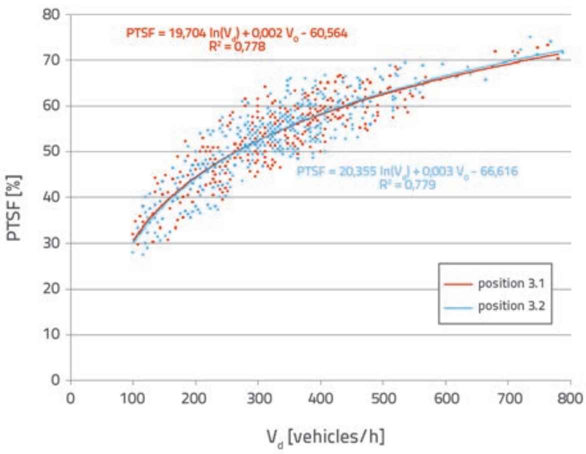

Figure 7. Field survey of PTSF before and after the 450 m passing zone (cross sections 3.1 and 3.2)

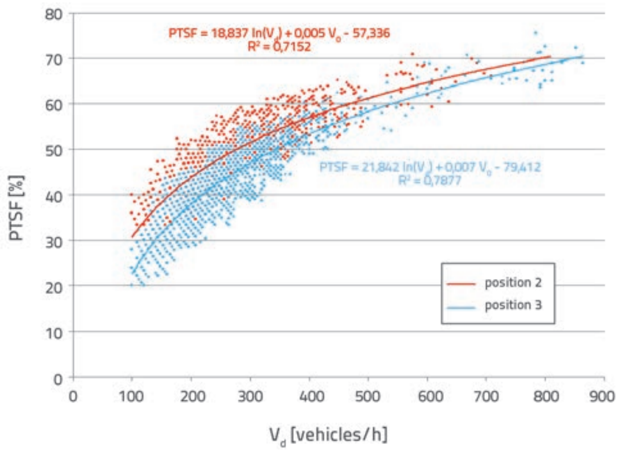

Figure 8. Field survey of PTSF before and after the 1100 m passing zone (cross sections 2 and 3)

4.2.5. Length and number of individual passing zones

As indicated above, HCM 2010 does not take into consideration the length and number of individual passing zones. Field survey results show that section length has a significant influence, as also shown by some earlier studies [16]. Field measurements conducted in cross sections before and after passing zones enable determination of the influence of such zones on the PTSF. The results relating to the influence of passing zones 450 m in length (zones between cross sections 3 and 4) and 1100 m in length are presented on Figures 7 and 8 (for the Salakovac – Grabovica direction).

The relationship between the PTSF values (curves in Figure 8) in cross sections immediately prior to and after the 1100 m passing zone (cross section 2 before, and cross section 3 after) reveals that the influence of this zone on PTSF is significant. On the other hand, the 450 m passing zone (diagram 6) has a very small influence of PTSF for traffic volumes of less than 250 vehicles/hour, while it has almost no influence on higher traffic volumes. This shows that the relationship of influences on PTSF exerted by passing zones of various lengths is much greater that the relationship of their lengths.

5. Conclusion

The field surveys show that the PTSF values deviate from calculations according to other models developed worldwide. This is due to different traffic flow conditions and to deficiencies of the models themselves. In addition, some models also propose the approaches [9-17] that can not easily be applied on B&H roads, as they focus on speed, and as they define in a different way the situation when vehicles are considered to be in a platoon. The following conclusions can be derived from the survey conducted in the paper:

- The comparison of survey results with the results obtained by analysed models reveals a difference in results that is due to the lack of adjustment to local conditions, and/or to model deficiencies.
- The illogicality of the HCM methodology, according to which the PTSF decreases with an increase in the opposing traffic volume, has been confirmed. The PTSF values obtained during field surveys increase with an increase in the opposing traffic volume.
- The influence of the percentage of heavy vehicles is negligible for the road with a good geometry (design speed of 80 km/h).
- The length and the number of individual passing zones exert a considerable influence on the PTSF.
- Short passing zones have a negligible influence on the PTSF, even in the case of small traffic volume.

The mentioned considerations show that existing methodologies must be either adjusted to also take into account the length of passing zones, or that they must be altogether replaced by a new methodology.

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