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17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

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THE IMPACT OF SELECTED ROAD AND TRAFFIC FEATURES ON TRAVEL SPEED ON TWO LANE HIGHWAY

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Abstract

The planning, designing and subsequent exploitation of a road network requires tools enabling rational decision-making with regard to the use of solutions (selection of geometry, traffic organization and management, equipment etc). Road capacity, which is one of the basic features characterising the individual elements of road infrastructure, plays a key role in the selection of a road's cross-section and the assessment of alternative solutions. Capacity estimation is inextricably linked to the assessment of traffic performance, through which it is possible to implement a qualitative approach to the process of road design and exploitation. The HCM and HBS methodologies are geared towards proper determination of the Level of Service (LOS) measures and subsequently to capacity estimation. Two-lane highways were divided according to their functions and road cross-section, which in turn led to the establishment of several classes of road sections homogeneous in terms of longitudinal gradients and the share of heavy vehicles, as well as road curvature (HBS). The basic measures of traffic performance are average travel speed and traffic density. Different traffic performance measures in the HCM and HBS methods and different analytical methods produce disparate traffic performance assessments for a given road section. In this paper, the authors present a comparison of the sensitivity of both methods to change in road features and traffic characteristics. Additionally, the paper describes selected studies on travel speed carried out in Poland on over 90 rural road sections in 2016-2017. It presents the research method, potential impact factors and variation of the studied road features, surroundings and traffic on travel speed. The authors conduct an analysis of interdependences between basic traffic parameters including traffic volume, speed and density in specific classes of road conditions and relate them to HBS findings. The analysis is aimed at developing a proprietary Polish method of estimating traffic performance and the capacity of two-lane highways. The research was carried out as part of a project named "Modern methods of calculating the road capacity and assessment of traffic conditions of roads outside municipal agglomerations, including express roads" [1] within the framework of a program financed by the National Center for Research and Development and the General Directorate for National Roads and Motorways.

Keywords: traffic performance, capacity, two-lane highways, research and analyses

1 Introduction

The HCM 2010/HCM 6 [2, 3] and HBS [4] methods for rural two-lane highways are used to analyse and design roads intended for continuous traffic, i.e. traffic whose course is not controlled by traffic control devices, such as traffic signals or interrupted because of subordinated entries to roundabouts. The methods allow determining traffic performance (LOS A – E (F)) and capacity on the analysed road section. They take into account the impact of geometrical features, traffic and access to the road, although the HCM method accommodates these fac-

tors to a considerably larger extent. The HBS method is designed for road sections of a certain standard of geometry and traffic organisation. The time interval used for calculations is usually 1 hour. Variability of traffic within an hour (quarterly traffic volumes) is incorporated into in the HCM method. The interdependencies between road and traffic features were elaborated e.g. on the basis of empirical research, and therefore reflect the local specificity of road and traffic solutions. The methods do not take into account random factors and disturbances such as poor weather conditions, incidents and road works, although these factors can markedly affect the operational conditions on the road during certain periods.
Differences in the number of factors included in the methods, their very design and the traffic performance measures used mean that the same factors have different impacts on the final result. It is therefore important to compare the methods' sensitivity to changes in factors, such as the road's longitudinal gradient, share of heavy vehicles and traffic volumes.
This analysis of the existing and widely used HCM and HBS methods was carried out in order to identify factors which have a potential to determine traffic performance on road sections, the size of their impact and traffic performance measures which are in use. This enabled proper preparation of the empirical research program for Polish roads. Research carried out in 2016-2017 and still ongoing is intended to culminate in the development of a calculation method that suits the local conditions.

2 Assessment of traffic performance on a section of a two-lane highway

Under the HCM method the criteria used to assess the level of service (LOS) consist of the average vehicle speed, percent time spent following and the percentage of free flow speed. These measures are used to assess the distinguished road classes. Additionally, it is possible to calculate road capacity. It is not possible to directly calculate critical traffic volumes for individual LOS_i, although it is possible to iteratively investigate critical traffic volumes. HBS enables the determination of the average speed of passenger cars moving in a traffic flow, as well as capacities and critical traffic volumes. In this method, speed and traffic density are criteria of LOS assessment. Traffic volume-speed-density dependencies are presented in the form of graphs for adopted classes of longitudinal gradient and road section curvature. Although in both methods the speeds used to assess traffic performance differ (HCM focuses on travel speed, whereas HBS relies on speed of passenger cars in the traffic flow), yet in certain circumstances both methods will yield corresponding results, e.g. on a section free of disturbances and with a high traffic volume, where the speed of the flow depends to a large extent on the speed of the slow moving vehicles. Comparing these two methods, one can rather use this measure. Another option is to determine traffic density on the basis of traffic volume and speed.

3 Sensitivity of HCM and HBS to changes in road and traffic features

The two method feature factors that are specific to one of them, e.g. lane and shoulder widths, entry density, lack of possibility of overtaking or traffic volume moving from the opposite direction are specific to HCM, while road curvature is specific to HBS, and those that common to both these methods. The paper compares the sensitivity of both methods to changes in the value of common factors.

3.1 Impact of heavy vehicles

The impact of heavy vehicles on speed in both methods depends on three factors: the share of heavy vehicles, a road section's longitudinal gradient and length of the road section with a given gradient and traffic volume. In the HCM method, these factors are used to select the appropriate passenger car unit for heavy vehicles, while in the HBS method they are used to select the graph of the average dependence of car speed on traffic volume. Figure 1 shows a comparison of the impact of heavy vehicles on the speed of flow when: section length is 1000 m, lane width is 3.5 m, shoulder width is 1.5 m, there are no exits, terrain is flat/1st class of vertical alignment and longitudinal gradient are at 5 %, overtaking capacity is at 100 %, design speed is 90 km/h, traffic volume is at 800, 400 and 200 P/h/ lane.

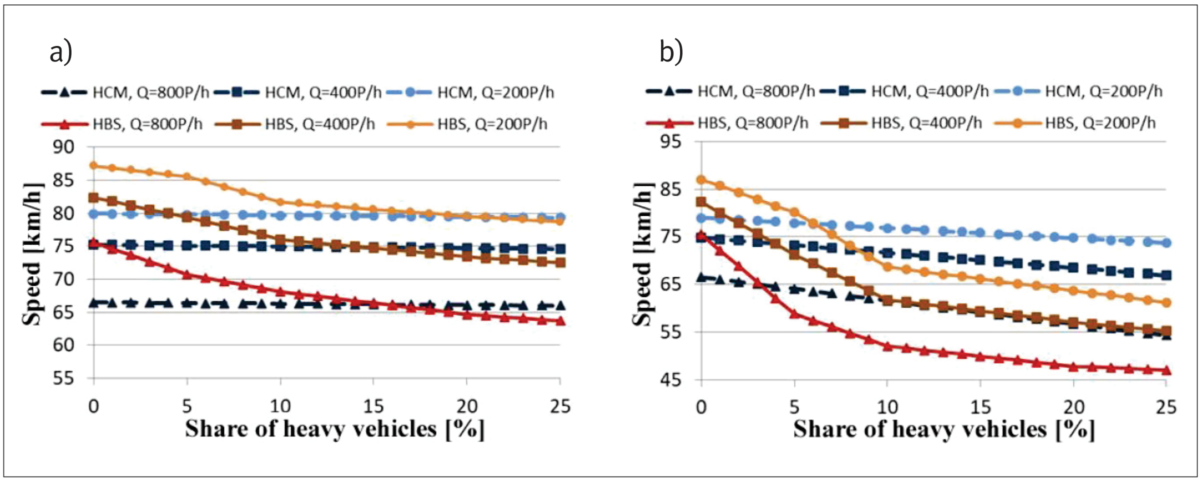

Figure 1 Impact of heavy vehicles on speed: a) flat terrain, b) longitudinal gradient 5 % (P/h – vehicles per hour)

The results indicate a much greater impact of heavy vehicles on speed for data assumed in the HBS calculations than in the HCM methodology. According to the HBS method, this effect is nonlinear. With a small share of heavy vehicles, speeds according to HBS are higher than according to HCM, and with a large share of heavy vehicles they are lower.

3.2 Impact of a road's longitudinal gradient

The authors made a comparative analysis of the influence of longitudinal gradient of the vertical alignment (Fig. 2) for a road section with the same geometrical parameters as in 3.1 above.

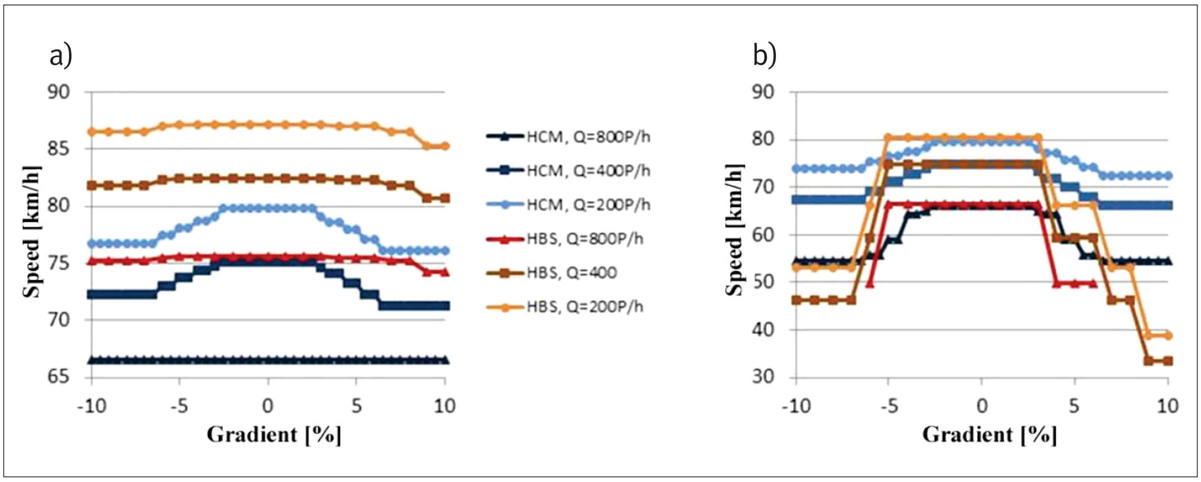

Figure 2 Impact of longitudinal gradient of road's on speed, with heavy vehicles share of traffic at: a) 0 %, b) 15 %

When traffic flow is constituted only of passenger cars (Fig. 2a), a slight reduction in speed resulting from longitudinal gradient is noticeable in both methods. According to the HCM method, it ranges from 0 to approx. 4 km/h depending on traffic volume, compared to approx. 1.5 to approx. 1.9 km/h according to the HBS method. With a 15 % share of heavy vehicle traffic (Fig. 2b), the HBS method reveals that a much higher speed reduction is caused by the longitudinal gradient. It is obvious that with a large proportion of heavy vehicles in the traffic, greater longitudinal gradients on the road cause a greater reduction in vehicle speed because passenger cars have less of an opportunity to overtake slow-moving heavy vehicles. The different values of gradient impact between the methods may also be related to assumptions underlying overtaking. According to HBS, overtaking occurs on sections with an additional lane, and according to HCM on the entire length of the section, but traffic moving from the opposite direction has a significant impact on overtaking.

3.3 Impact of traffic volume on the analysed lane

The HBS method allows determining traffic performance in relation the traffic volume only on the analysed lane. In micro-simulations carried out during work on the method, the same traffic volume was assumed on the lane carrying traffic from the primary and the opposite directions [5]. HCM, on the other hand, allows to take into account traffic in the primary and opposite directions. The impact of traffic volume on the speed of the traffic flow for a road section with geometrical parameters as in 3.1 above, and further assuming a 50 %/50 % directional distribution of traffic, is shown in Fig. 3. For the assumed input data, the i% longitudinal gradient of the road have a negligible effect on the results.

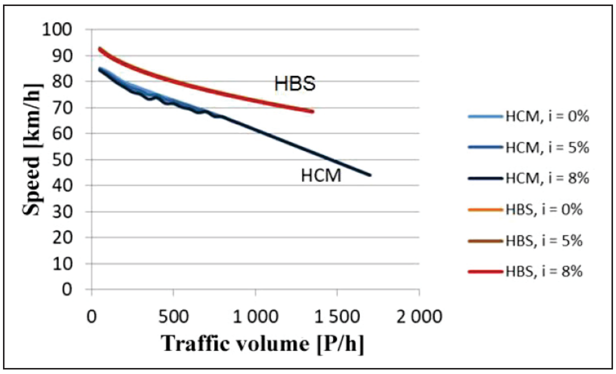

Figure 3 Impact of traffic volume on the analysed lane on vehicle speed

4 Empirical studies on travel speeds on two-lane roads in Poland

In 2016-2017 studies on travel speed were carried out in Poland on over 90 rural road sections as part of project [1]. The research used the technique of video recording at the initial and final parts of road sections as well as travels in a research vehicle equipped with video cameras and GPS navigation. The measurements allowed determining the travel speed of each vehicle, traffic volume, its directional structure as well as the type of vehicles and the density of the flow during the distinguished durations. Additionally, information describing the road and its surroundings was also recorded in the database. The basic descriptors of a road's cross-section include lane width and type of shoulder (paved, unpaved). Their impact on travel speed already manifested itself at the preliminary stage of analysis. (Fig. 4). An increase in lane width (Fig. 4a) translates into an increase in the average speed of demand flow. The graph shows the average speed values including outliers in a given lane width band (solid line) and an average value excluding these speeds (dashed line). A much higher average travel speed was recorded on research sites having paved shoulders (Fig. 4b). Part of the sections covered by the measurements are located near areas with dense or dispersed building development, others run through farmlands, and the surroundings of the remaining sections are constituted of a combination of the two. Figure 5 shows how average travel speed varies depending on the surroundings of the sections examined. Lower average travel speeds occur on sections with housing developments, and higher on sections surrounded by farmland.

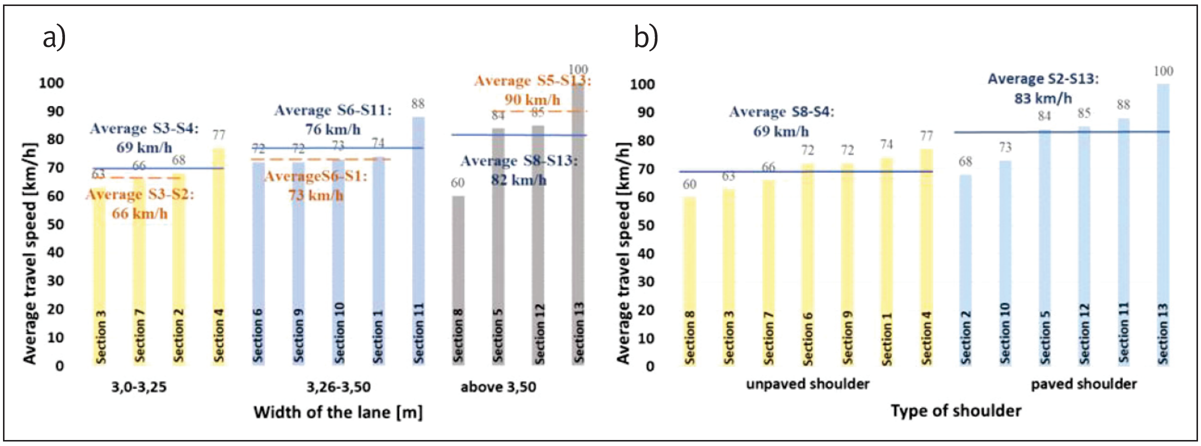

Figure 4 Travel speed on sections: a) of variable lane width, b) of variable type of shoulder

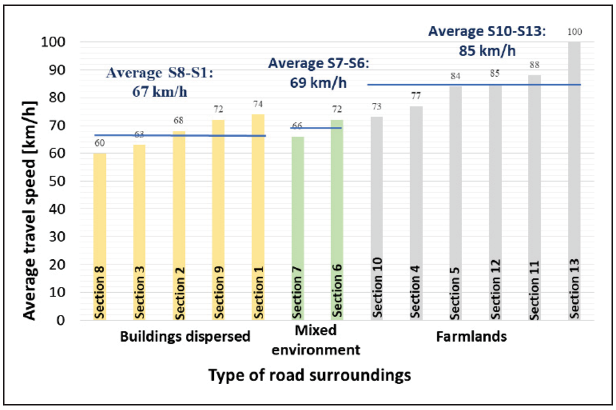

Figure 5 Travel speeds on sections with different types of surroundings

The effect of traffic volume and the share of heavy vehicles on the travel speed on sections of the first and third class of curvature and first class of vertical alignment (according to HBS) is shown in Figure 6.
At low road curvature rates and conditions more conducive to overtaking (Fig. 6a), there is a greater variation in vehicle speed and the impact of the share of heavy vehicles. Significant road curvature rate (3rd class of curvature: 100-150 g/km) with reduced possibility of overtaking causes a decrease in the speed of road traffic and has a marked impact on the speed of heavy vehicles (Fig. 6b).

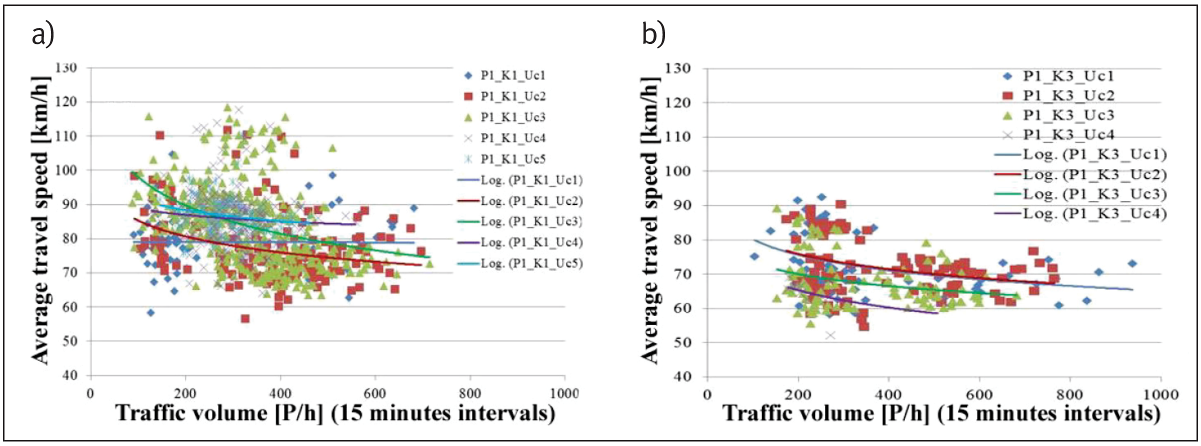

Figure 6 Travel speed depending on traffic volume in the primary direction and share of heavy vehicles for road curvature class/ vertical alignment class in HBS; a) 1/1, b) 3/1. Data from 38 research sites

5 Regression analysis of travel speed

The regression analysis was conducted using the STATISTICA software package. The linear multiple regression model for an n-element theoretical sample is as follows:

$$y_i = \beta_0 + \beta_1 \cdot x_{1i} + \beta_{2i} + \ldots + \beta_k \cdot x_{ki} + \varepsilon_i \quad \text{for } i = 1,2,\ldots,n \tag{1}$$

Where:
β_j – model's parameters,
ε – random element.

The following independent variables were used:
f_1 – average traffic volume [P/5min]
f_2 – average traffic density [P/km/pas]
f_3 – average share of heavy vehicles [%]
f_4 – average traffic volume moving in the opposite direction [P/5min]
f_5 – average lane width [m]
f_6 – type of shoulder (paved-1, unpaved-0)
f_7 – density of exits [exit/km]
f_8 – section's curvature [g/km]
f_9 – average weighted longitudinal gradient [%]
f_{10} – share of sections suitable for overtaking [%]
f_{11} – average traffic volume on road's cross-section [P/5min]
f_{12} – presence of dispersed housing development along the road –0/1 variable.

Of the more than a dozen regression models built for averaged data in 5-minute intervals taking into account different sets of independent variables (f_1 – f_{12}), two are presented below. The two models below were built separately for geometric data, surroundings-related data and traffic-related data ascertained for densities of less than 25 [P/km/lane]. The first model takes into account the average traffic volume on the analysed lane f_1, while the second incorporates traffic density v_2. Both models have the same design and the same impact factors and a very similar coefficient of determination. The value of the R^2 coefficient is not high, which indicates an average goodness of the fit of the models to empirical data. Statistically significant factors occurring in the models include the effects taken into account in the HBS method, i.e. curvature, longitudinal gradient and the share of heavy vehicles, as well as factors included in the HCM method, i.e. the lane and shoulder widths and road surroundings (indirectly related to the division into road classes in HCM). The presence of a paved shoulder was included in variable f_5 – lane width. The interaction of variables f_3 and $f_9$concerns only positive longitudinal gradients.

$$V = 606{,}5 - 0{,}16 \cdot f_1 + 12{,}43 \cdot f_5 - 0{,}083 \cdot f_8 - 5{,}56 \cdot f_{12} - 0{,}082 \cdot f_3 \cdot f_9 \tag{2}$$

$$V = 517{,}3 - 0{,}47 \cdot f_2 + 11{,}76 \cdot f_5 - 0{,}079 \cdot f_8 - 4{,}67 \cdot f_{12} - 0{,}087 \cdot f_3 \cdot f_9 \tag{3}$$

6 Conclusions

The generic structure of vehicles and drivers' behaviours on Poland's rural two-lane highways are closer to those in Germany than in America, mainly due to the geographical location. Analysis of extant literature reveal differences between the German and American approaches, and the models used to determine the levels of free flow differ in terms of the adopted measures of traffic performance. Sensitivity analysis revealed significant differences between the results of examinations of the same impacts of both methods. The study of traffic volume's impact on speed reveals that at the same values of longitudinal gradient vehicle speeds in the HBS method are higher than in the HCM method. The HCM method also assumes a linear relationship between speed and traffic volume, whereas the HBS method assumes a non-linear dependence. These and other differences between the methods show different impacts of a given factor on drivers' behaviour and, consequently, on the travel speeds in Germany and the US. Polish models developed on the basis of the same impact factors show an average fit coefficient to empirical data. Both regression models are built similarly and capture factors that occur in both the German and American methods. The results of the research indicate a need to identify the configuration of road, surroundings and traffic features that is slightly different from the configuration of the German method, in order to ensure that reality is better represented in mathematical models.

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