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ANALYSIS OF SPEED OF FREE TRAFFIC FLOW ON LONGITUDINAL DECLINING SLOPE

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Key words: *speed, free traffic flow, longitudinal declining slope.*
Abstract: *Movement of multiple vehicles is conducted in certain order, thus forming a traffic flow which exists in a specific speed. The subject of this paper is the analysis of dependency of speed of nonhomogenous free traffic flow from values of longitudinal declining slope with use of deterministic methods which give optimal description of speed of free traffic flow in two-lane roads. For this paper, field measurements of three different locations with three different values of longitudinal declining slope have been taken, aiming to calculate the speed of free traffic flow, and have been subsequently analyzed with use of HCM 2010 and compared to speed limitations.*

INTRODUCTION

Speed is one of the basic perimeters in description of condition of free traffic flow. When describing laws of movement of motor vehicles with consideration to circumstances of movement of vehicles in a traffic flow and level of interaction between vehicles, middle spatial and middle time speed are given specific titles: speed of free traffic flow, speed of normal traffic flow, speed of saturated traffic flow and speed of forced traffic flow. Term speed of free traffic flow is related to the traffic flow and means that all vehicles in a traffic flow on observed part of the road are moving in identical or similar conditions of movement related to movement of indvidual vehicles on observed part of the road. [1]

According to HCM manuals, the speed of traffic flow no longer has a primary role in defining the level of service, wheras in domestic manuals the speed of traffic flow still has a role of priority indicator. Value of speed of free traffic flow in two-lane roads is in a complex functional dependency of percentages of time delay, different types of vehicles, engine-dynamics characteristics of vehicles and road characteristics (including types of terrain), and it is directly equal with the speed of free traffic flow in service level A, making it a basic precondition for analysis of capacity and level of service of roads.Research of dependency of speed in free traffic flow to size of longitudinal slope is related to the need of determining travel time and expenses of exploatation of road users.

METHODOLOGY

Two-lane roads are roads with undivided road surface with two traffic lanes, where each traffic lane is used for one way traffic. Overtaking of slower vehicles requires use of traffic lane used by vehicles coming from the opposite direction. Needed elements to conduct overtake are visibility and vacancy of traffic from the opposite direction. Two-lane roads are a key element in road systems in most of the countries. They perform different functions, are located in all geographical areas and are a service for a wide range of traffic. Efficient mobility is the basic function of two-lane roads which connect main traffic generators or serve as primary connections in national road network.

Roads on a flat area or a mildly undulated area usually have higher geometrical standards (and desired speed) than roads with similar traffic volumes in hilly areas. Where there is an obvious reason for lower geometrical standard (e.g. uneven or steep terrain) drivers expect to travel in lower speed and are more willing to accept and adapt to the lower geometrical standards than in situations where there are no aforementioned reasons.

Operations in longitudinal declining slope have not been separately treated in analysis of level of services. Operations on a mild declining slope (less than 3%) can be approximately leveled to those of a flat road. On higher slopes, operations in declining slope are somewhere in the middle between those observed on a horizontal road and on a rising slope for equivalent traffic flow and road characteristics. This is especially related to heavy goods vehicles. The biggest quality of traffic service is established when drivers can drive their vehicles with desired speed. [1]

HYPOTHESIS

The speed of the free traffic flow is in functional dependency of various road characteristics and especially the length of rising slope, and it is a variation of values of speed under the value of longitudinal declining slope. Basic premise in creation of this work is an assumption that increase of declining slope also increases the value of speed of movement of vehicles in free traffic flow.

Method HCM 2010 is a new method in analysis for a single traffic direction, differing from standard analysis of both directions. Entry data taken from the database are: PGDS, K factor, D factor, PHF, urban/suburban, terrain, number of traffic lanes (N), traffic signs, heavy goods vehicles (%), recreational vehicles (%), functional class, length of the route, speed limit, divided directions, terrain slope, width of the traffic lane, width of side banks.

SPEED OF FREE TRAFFIC FLOW

Speed of the free traffic flow can be calculated on basis of field data as displayed in the following equation:

$$FFS = S_{FM} + 0{,}0125\frac{V_f}{f_{HV}} \quad (1)$$

FFS – Speed of free traffic flow [km/h]
S_{FM} - Medium speed of traffic measured on the field [km/h]
V_f – Observed traffic flow for the time period of data acquiry [veh/h]
f_{HV} – Factor of participation of heavy goods vehicles. [3]
Analysis of two-lane roads has been altered from methods used in HCM 2000. The procedures in HCM 2010 allow procedures for analysis of one direction. This procedure includes additional class of the road. The main reasons of this procedure are average travel speed, percentage of speed of free traffic flow on two-lane roads. [4]

ANALYSIS OF SPEED BEHAVIOUR IN RELATION TO LONGITUDINAL DECLINING SLOPE

Selected crossings where the research has been made are on two-lane routes, parts of highways M-17 and M-17.2., located in Republika Srpska. The aim of the research is to reach a speed of free traffic flow in different longitudinal terrain slopes. Measurements have been made on three sections with various longitudinal slope (-0.017 [%] ; -1,92 [%] i -5 [%]).
Speeds of vehicles were measured with use of a measurement device (speed radar). All measurement were done for one direction only and only on a longitudinal declining slope. Influence of intersections has been avoided, as all three sections are located in non-urban roads.

The first section is located on a declining slope of -0,017 [%], on a section titled 219 by the Public company "Putevi Republike Srpske (Roads of Republika Srpska)", a part of highway M-17, 200 [m] away from intersection 26 (M-4/M-17). Speed limit in this intersection is 60 [km/h], speed measure has been in one direction only and the speed of vehicles driving down the declining slope has been measured. Measure has been done in conditions of a dry road; a sample has 250 values of measured speeds. Analysis of speeds by traffic flow structure has been made

Table 1. *Calculation results on the first section*

CALCULATION RESULTS				
	PC	HV	BUS	M
Medium value	53,493	53,294	59	56
Standard error	0,548	1,572	2	0
Non-perimeter middle	54	52,5	59	56
Standard deviation	8	9,167	2,828	
Sample variation	63,996	84,032	8	
Interval of variation	59	49	4	0
Lowest value	14	22	57	56
Highest value	73	71	61	56
Sum of all values	11394	1812	118	56
Number of observations	213	34	2	1
First highest value	73	71	61	56
First lowest value	14	22	57	56
Interval of precision (95,0%)	1,08	3,198	25,412	

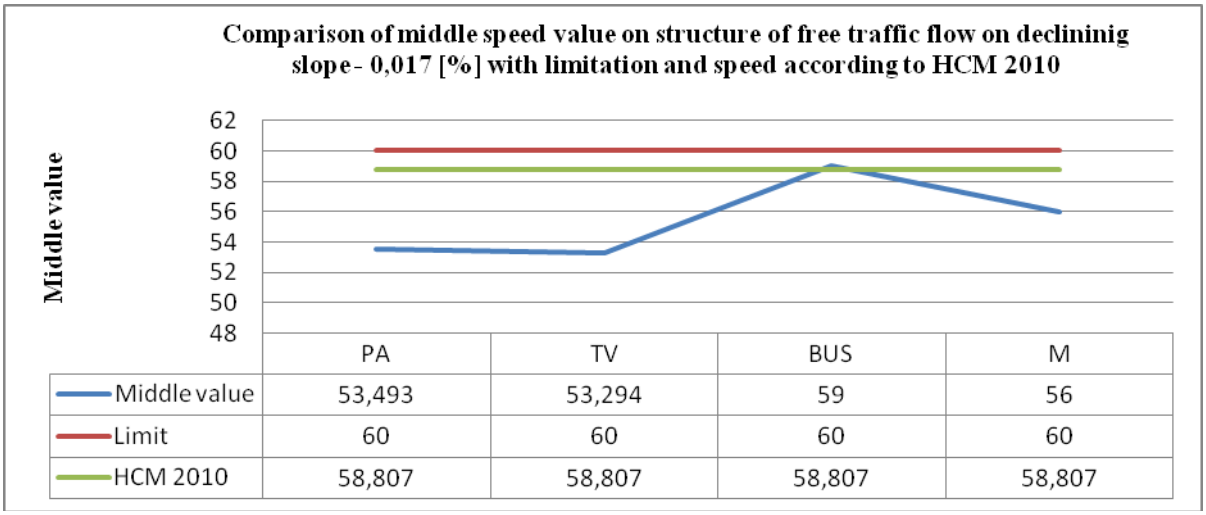

Fig.1. *Comparison of middle speed with limitation and speed according to HCM 2010*

With analysis of measured values on the field using HCM 2010 we extrapolated values describing the condition of the traffic flow, as shown in diagram 1, where we see that drivers observe speed limit, and the biggest deviation from middle speed measures in comparison to calculated speed according to HCM 2010 comes from heavy goods vehicles by 5,513 [km/h]. The second section is located on a declining slope of -1,92 [%] on a [%], on a section titled 451 by the Public company "Putevi Republike Srpske (Roads of Republika Srpska)", a part of highway M-17.2, 11.600 [m] from intersection 209 (M-17/M-17.2). Speed limit in this part of the road is 80 km/h, speed measure has been in one direction only and the speed of vehicles driving down the declining slope has been measured. Measure has been done in conditions of a dry road; a sample has 250 values of measured speeds. Categorization of vehicles has been made.

***Table 2**. Calculation results on the second section*

CALCULATION RESULTS					
	PC	HV	BUS	M	HGV
Medium value	64,607	67,618	65,75	74	54
Standard error	0,969	1,586	8,159	0	0
Non-perimeter middle	64	67	64	74	54
Standard deviation	12,555	13,827	13,827		
Sample variation	157,617	191,199	266,25		
Interval of variation	80	66	33	0	0
Lowest value	35	35	51	74	54
Highest value	115	101	84	74	54
Sum of all values	10854	5139	263	74	54
Number of observations	168	76	4	1	1
First highest value	115	101	84	74	54
First lowest value	35	35	51	74	54
Interval of precision (95,0%)	1,912	3,16	25,964		

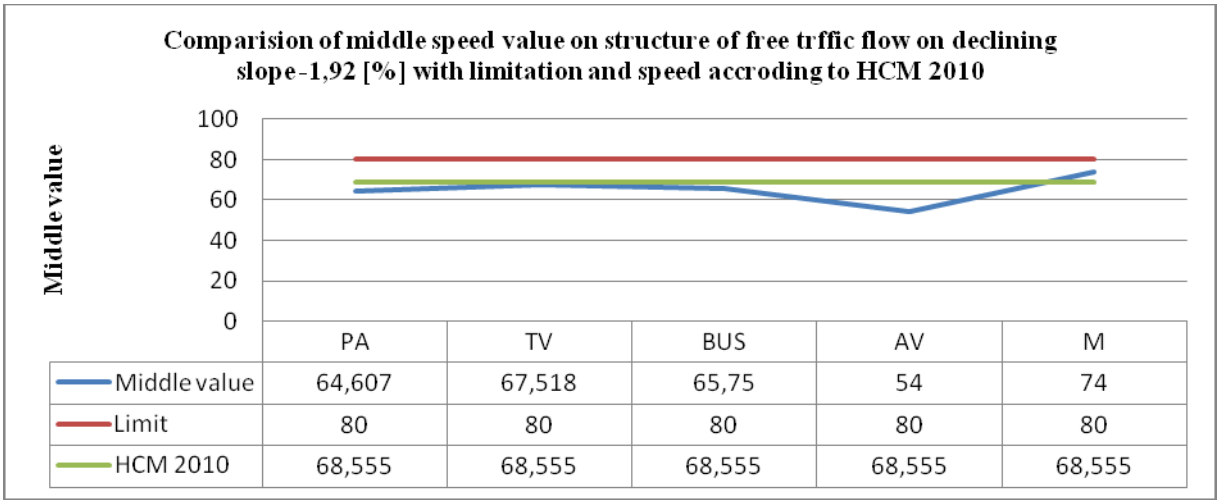

***Fig. 2.** Comparison of middle speed with limitation and speed according to HCM 2010*

With analysis of measured values on the field using HCM 2010 we extrapolated values describing the condition of the traffic flow, as shown in diagram 2, where we see that drivers observe speed limit, and the biggest deviation from middle speed measures in comparison to calculated speed according to HCM 2010 comes from auto transporters by 14,555 [km/h]. The third section is located on a declining slope of -5 [%], on a section titled 451 by the Public company "Putevi Republike Srpske (Roads of Republika Srpska)", a part of

highway M-17.2, 10400 [m] from intersection 26 (M-17/M-17.2). Speed limit in this section is 80 [km/h], speed measure has been in one direction only and the speed of vehicles driving down the declining slope has been measured. Measure has been done in conditions of a dry road; a sample has 250 values of measured speeds. Categorization of vehicles has been made.

***Table 3**. Calculation results on the third section*

CALCULATION RESULTS					
	PC	HV	BUS	M	HGV
Medium value	74	75,912	69,667	68	74
Standard error	1,001	1,346	7,055	0	6
Non-perimeter middle	73	74	67	68	74
Standard deviation	12,384	12,838	12,22		8,485
Sample variation	153,368	164,814	149,333		72
Interval of variation	77	59	24	0	12
Lowest value	43	52	59	68	68
Highest value	120	111	83	68	80
Sum of all values	11322	6908	209	68	148
Number of observations	153	91	3	1	2
First highest value	120	111	83	68	80
First lowest value	43	52	59	68	68
Interval of precision (95,0%)	1,9780712	2,6736442	30,35666		76,23723

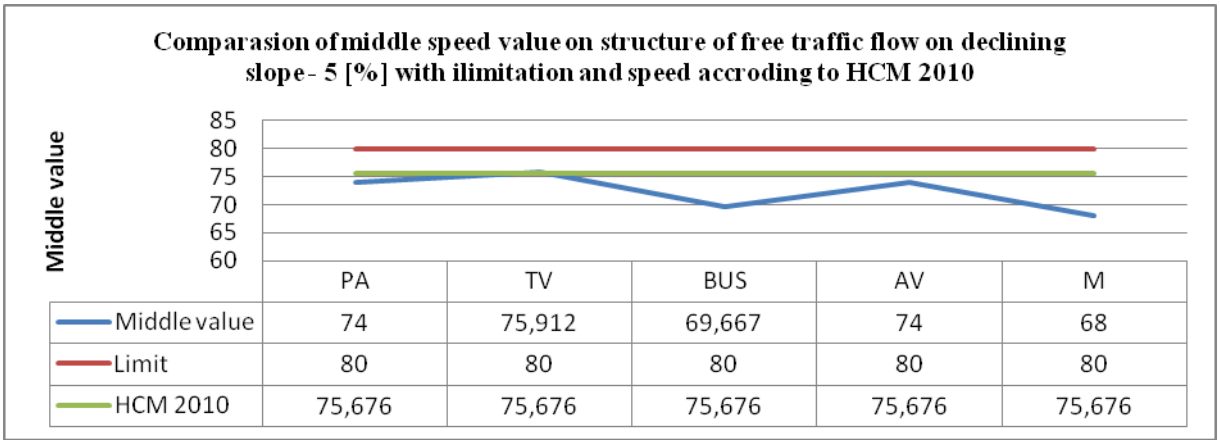

***Fig. 3.** Comparison of middle speed with limitation and speed according to HCM 2010*

With analysis of measured values on the field using HCM 2010 we extrapolated values describing the condition of the traffic flow, as shown in diagram 3, where we see that drivers observe speed limit, and the biggest deviation from middle speed measures in comparison to calculated speed according to HCM 2010 comes from motorcycles by 7,676 [km/h].

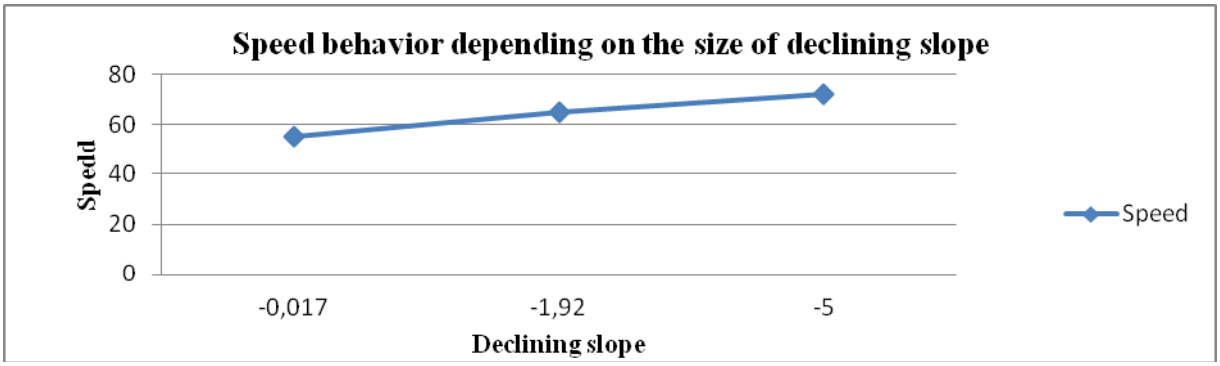

***Fig. 4.** Speed behavior depending on the size of declining slope*

The analysis established, as seen on diagram 4 that as the size of declining slope rises the speed of movement of vehicles also rises, thus proving our hypothesis.

DISCUSSION AND CONCLUSIONS

Through analysis of speed of movement of vehicles measured on field in various levels of longitudinal declining slope, and specifically in this case, a starting hypothesis that the size of slope influences the speed of free traffic flow has been confirmed. On the first section with a longitudinal slope of -0.017 [%] the average speed of movement of vehicles is 55,447 [km/h], on the second section which is located on the slope of -1,92[%] the average speed of movement of vehicles is 65,195 [km/h] and on the third section which is located on the slope of -5 [%] the average speed of movement of vehicles is 72,34 [km/h]. If we compare middle speeds of movement of vehicles on different longitudinal slopes, we reach a data that speed increased by 9,748 [km/h] in increase of slope by 1,903 [%], and in the increase of slope by 4,983 [%] the middle speed of movement of vehicle increased by 16,893 [km/h].

For further research more attention should be given to observation and collecting of information on speeds of movements of vehicles, which can be of significant help for planning and creation of a local manual for highway capacity. Also, this would allow for removal of any omissions in this routes before they receive unwanted consequences.

LITERATURE

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АНАЛИЗ НА СКОРОСТТА НА СВОБОДЕН ПОТОК НА ТРАФИК ОТ НАДЛЪЖЕН НАКЛОН

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Ключови думи: *скорост, свободен поток на трафика, надлъжно намаляващ наклон.*

Резюме: *Движението на няколко превозни средства се извършва в определен ред, като се образува трафик, който се осъществява с определена скорост. Предмет на настоящата статия е анализ на зависимостта на скоростта на нехомогенния свободен поток на трафика от стойността на надлъжния намаляващ наклон с използване на детерминистични методи, които дават оптимално описание на скоростта на свободния поток на трафика в двулентови пътища. В този доклад, са представени полеви измервания на три различни места, с три различни стойности на надлъжен намаляващ наклон, които са предприети, с цел да се изчисли скоростта на свободния поток на трафика, и впоследствие са анализирани с използване на метод HCM 2010 и сравнени с ограниченията на скоростта.*