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IMPACT OF TRAFFIC VOLUME AND COMPOSITION ON THE CHANGE IN THE SPEED OF TRAFFIC FLOW

Summary. *The problem of the change in the speed of traffic flow at different traffic volumes and compositions is researched in this study. The section of the road network with different geometric parameters (descent, ascent and horizontal section) was chosen for the study. The method of investigation of traffic flow`s speed and factors which have an impact on the reduction of road network capacity are analyzed. The change in the coefficients of the unevenness of traffic flow by hours of the day in the studied area was determined and a graph of the distribution of traffic volume by hours of the day was built. A diagram of the section was built to determine the speed of the traffic flow, on which the movement along the horizontal section, uphill and downhill movement is present. It was established that at a traffic volume of 700–800 p.c.u./h, the traffic flow moves at a constant speed (up to 10–15 km/h). Cumulative curves of traffic flow speed` distribution characterizing modes of traffic flow on the road network were built. It is determined that at volume-capacity ratio* $0< z \leq 0{,}4$ *on three investigated sections traffic flow moves with the speed from 35 km/h to 59 km/h. In the specialized software product PTV VISSIM, the simulation of the traffic flow on the horizontal section, ascent and descent has been developed. Using the MATHLAB software environment, it is shown how the speed of the traffic flow changes depending on the volume-capacity ratio and the share of the heterogeneous traffic flow. It was established that the highest speed of the flow is observed during the downhill movement – 58.62 km/h at the volume-capacity ratio – 0.13 and the share of heterogeneous traffic flow – 1.0 (100 % cars). At a volume-capacity ratio of 0.88 and existing road conditions, the speed of traffic flow on the horizontal section and during uphill movement is almost the same (the average deviation is 6 %). It can be explained by the fact that at a volume-capacity ratio of 0.88, traffic flow is in the traffic jam, hence, the speed of movement on the three sections is the same.*

Keywords: *road network, traffic flow, traffic volume, speed of movement, capacity, volume-capacity ratio, traffic simulation, field research, geometric parameters.*

1. INTRODUCTION

With the increase in the motorization level, many questions arise that are related to the functioning of road transport, road safety, rational use of the road network, and the speed of traffic flow. Undoubtedly, the most important task is ensuring the safety of road users [1, 2]. According to statistics on traffic accidents, the main cause of traffic accidents, which resulted in the death and injury of road users, is the inconsistency of the selected speed with specific road conditions – more than 30 % [3, 4]. This problem can be partially solved by identifying the regularities of the influence of the speed of the traffic flow on the capacity with different geometric parameters (descent, uphill and horizontal section). The availability of such methods will make it possible to scientifically substantiate the areas of effective application of project solutions and, thereby, to improve the quality of road traffic organization [5].

2. PROBLEM STATEMENT

One of the main problems of the city's road network congestion in the conditions of the growth of the car fleet and the volume of transportation is the uniformity of the traffic of the road network, volume-capacity ratio at its sections and the speed of the traffic flow [1, 6–8].

It is known that the geometric parameters of the roadway (length of ups and downs, number of traffic lanes), as well as traffic composition and volume are the most important factors influencing the speed of the flow. It has been studied that the average speed of the flow on slopes up to 40‰ decreases by 15 km/h compared to horizontal sections [9]. Traffic composition and volume affect the uniformity of the traffic flow. The deviation of the speed from the uniform one increases with the increase in traffic volume. The deviation of the flow speed at high traffic volume can be explained by the occupation of the lane with vehicles and the formation of a column on the sections between intersections [8, 10].

The dependence on traffic flow composition is explained by the difference in the dynamism and speed of movement of freight transport and cars [2]. The most uniform is a complete freight flow (or bus flow). In this kind of flow, a smaller number of maneuvers is observed, which ensures greater uniformity of flow movement [6]. The most uneven movement will be observed in the flow with a significant share of cars (60 %) and along with it, there are trucks that, due to the peculiarities of the movement, create obstacles for cars that move more dynamically [10]. As a result, the number of braking, accelerating and other maneuvers increases, and forced groups of cars are formed. All these factors directly affect the overall evenness of traffic flow.

3. RELEVANCE OF THE STUDY

The capacity and speed of movement on the road network before ascents, descents and horizontal sections depend on many factors. They are road-planning factors (relief of the area, the number and width of traffic lanes, the presence of curves in the plan and profile, urban development, etc.); transport factors (volume and speed of traffic, traffic flow composition, etc.); environmental factors; regulatory factors (duration of permissive traffic light signal, presence (or absence) of parking zones, etc.); psychophysiological characteristics of drivers. These factors significantly affect the speed of traffic flow. Therefore, it is relevant to study the change in the speed of the traffic flow at different traffic volumes and compositions with different geometric parameters (descent, ascent and horizontal section).

4. AIM AND THE TASKS OF THE STUDY

The aim of the study is to research the change in the speed of the traffic flow at different traffic volumes and compositions. Therefore, it is necessary to carry out field studies in the high-speed mode of traffic flow on the sections of the road network with different geometric parameters (descent, ascent and horizontal section).

The following tasks have been formulated to achieve the goal:

- to analyze the methods of research of traffic volume, speed, and composition;
- to develop the method of performance of traffic simulation in program software PTV VISSIM;
- to study the change in traffic speed at different traffic volumes and compositions.

5. ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

The successful operation of the road transport complex depends on the efficiency of its components. The main elements of the city's road transport complex are traffic flows, road network and traffic management [2].

The speed of the traffic flow is the primary indicator affecting the total costs of the road transport complex [11]. The speed characteristics of urban traffic are determined by the presence of a speed limit by road traffic rules, traffic intensity, the presence of pedestrian and bicycle traffic, the possibility of using multi-lane traffic, etc.

In the city, the efficiency of transport operation is achieved if traffic flow moves at an optimal speed [3]. The optimal speed is the speed that would ensure the minimum total costs for road maintenance and vehicle operation [10].

The analysis of the road network parameters showed that about 60 % of the streets do not meet modern operational requirements for speed parameters. All dangerous areas can be divided into two groups:

- the first group: permanently dangerous areas caused by road design features (narrowing of the roadway, serpentines, long or steep descents, etc.);
- the second group: temporarily dangerous areas, where it is difficult to predict the time of occurrence of a natural and climatic factor (solar glare, fog, ice, etc.).

An important indicator that characterizes the efficiency of highway operation is the volume-capacity ratio (z) – the ratio of traffic volume (N) to the roadway capacity (P) [1, 7, 12]. At volume-capacity ratio z=0.3 – 0.45, the most stable traffic flow is observed. Changing lanes is practically unlimited. The closer the z value is to one, the higher the traffic flow density, the lower the speed and the more difficult the traffic conditions [13].

To achieve uniform traffic on the arterial street, it is necessary that the volume-capacity ratios of individual sections do not have sharp differences and are in the range of 0.3–0.45. In the presence of such differences, the driving speed on the street decreases, and the risk of road accidents increases [7, 13]. Therefore, volume-capacity ratios assessment on the section and the development of measures to improve traffic conditions is one of the tasks during the improvement of traffic management methods. It will make it possible to eliminate indicators of volume-capacity ratio that exceed optimal values, and to equalize indicators on individual sections to ensure uniform movement [13–15].

Based on the above, it can be concluded that one of the most important factors that characterize the uniformity of traffic on the road network is the volume-capacity ratio at its sections and the speed of the traffic flow [10].

6. PRESENTING MAIN MATERIAL

It is necessary to choose a section of the road network where the experiment will be carried out to study the influence of the composition and intensity of the traffic flow on the average speed of its movement. The following restrictions were made to assess the influence of the geometric parameters of the roadway on the speed of movement:

- the research should be carried out on the street with one lane in each direction;
- there should be descent (up to 40 ‰), ascent (up to 40 ‰) and horizontal section;
- there should be a significant share of heavy and public transport;
- the peak and off-peak periods should be clearly expressed.

The results of the study of the traffic flow speed under this system of restrictions make it possible to choose a section of the road network in the city of Lviv. A section of the street of district importance (Sakharova St.) between the intersections of Sakharova – Stryiska and Sakharova – Knyagyni Olgy was chosen. There is an uphill and downhill section of the street; a horizontal section is observed (between the intersections of Sakharova – Boykivska and Sakharova – Knyagyni Olgy streets), and the number of traffic lanes is one in each direction.

The maximum hourly traffic volume and composition in the studied section (horizontal section, descent and ascent) were determined by results of the field study. As a result of field studies, the value of the coefficients of the daily unevenness of the traffic volume was established (Fig. 1).

A graph of the distribution of traffic volume by hours in the studied area was constructed (Fig. 2).

Graphs of peak loads of traffic volume in the studied area were constructed. The composition of vehicles moving on the road network of the city is determined. The percentage ratio of transport categories is shown in the diagram (Fig. 3).

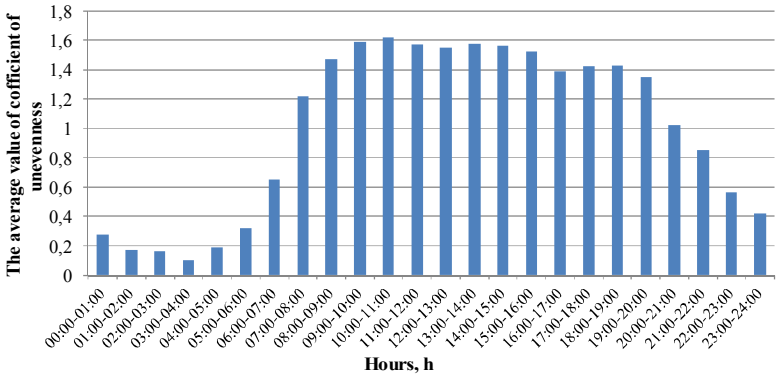

Fig. 1. The graph of changes in the coefficients of the unevenness of traffic flow by hours in the studied area

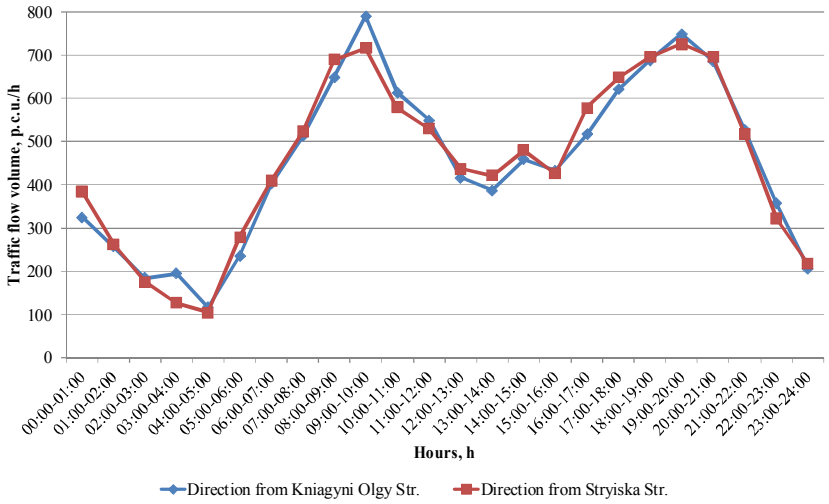

Fig. 2. Graph of the distribution of traffic volume by hours in the studied area

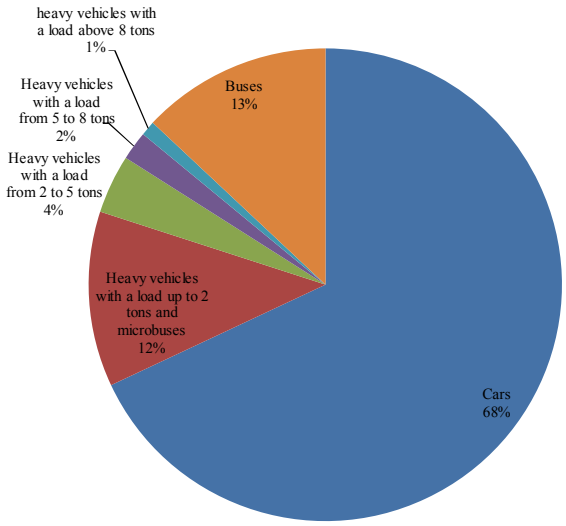

Fig. 3. Diagram of traffic flow composition in the studied area

The analysis of the field research data by traffic volume composition in the studied area showed that:

– cars prevail in the studied area (68 %), a significant part is occupied by public transport (13 %), freight transport is mainly up to 2 t (12 %), heavy vehicles with a load from 2 to 8 tons (6 %)

usually serve the retail network, post office, garbage collection, delivery of construction cargo, work of special emergency equipment, etc.;

– the studied section operates during the morning peak period in a busy mode: traffic delays are from 15 minutes or more;
– the capacity of the studied area is reduced before the ascent.

Measurements of the speed of transport units on a horizontal section, ascent and descent were carried out to study the influence of the traffic volume and composition. The scheme of the section for determining the speed of the traffic flow is shown in Fig. 4.

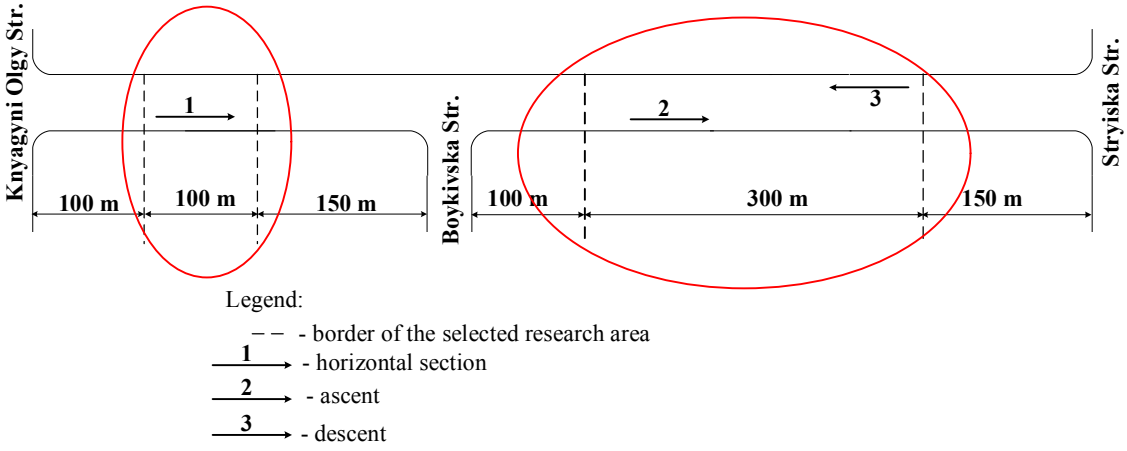

Fig. 4. The scheme of the section for determining the speed of the traffic flow

Empirical dependences of speed from the traffic volume, composition, and density were constructed based on the results of field studies.

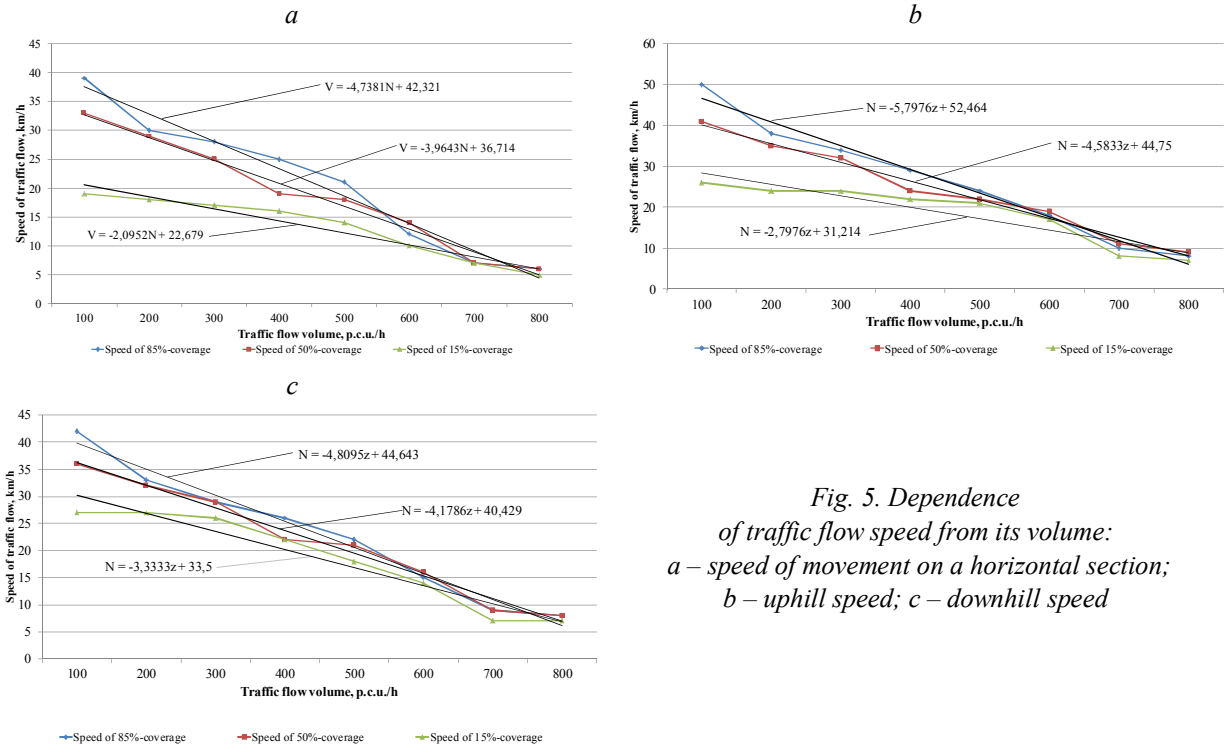

Fig. 5. Dependence of traffic flow speed from its volume: a – speed of movement on a horizontal section; b – uphill speed; c – downhill speed

Having analyzed the graphs shown in Fig. 5, we can see that at a traffic volume of 700–800 p.c.u./h, the lines intersect in the graph. As a result, the traffic flow moves at a constant speed (up to 10–15 km/h).

These indicators are valid for the averaged parameters of the sections of the road network in the city of Lviv, where speed measurements were carried out. The indicated traffic volume during the peak period was taken to analyze vehicle speed measurements on different sections of the road network. However, each considered section has its own capacity. Therefore, volume-capacity ratios were calculated to compare the results obtained on different sections of the road network.

Measurements in the speed of traffic flow were carried out on the horizontal section, descent and ascent in the peak period. Cumulative curves of flow velocity distribution were constructed. Speed values of 85 % – coverage, which characterizes the modes of movement of traffic flow on the road network, were used to build the graph (Fig. 6).

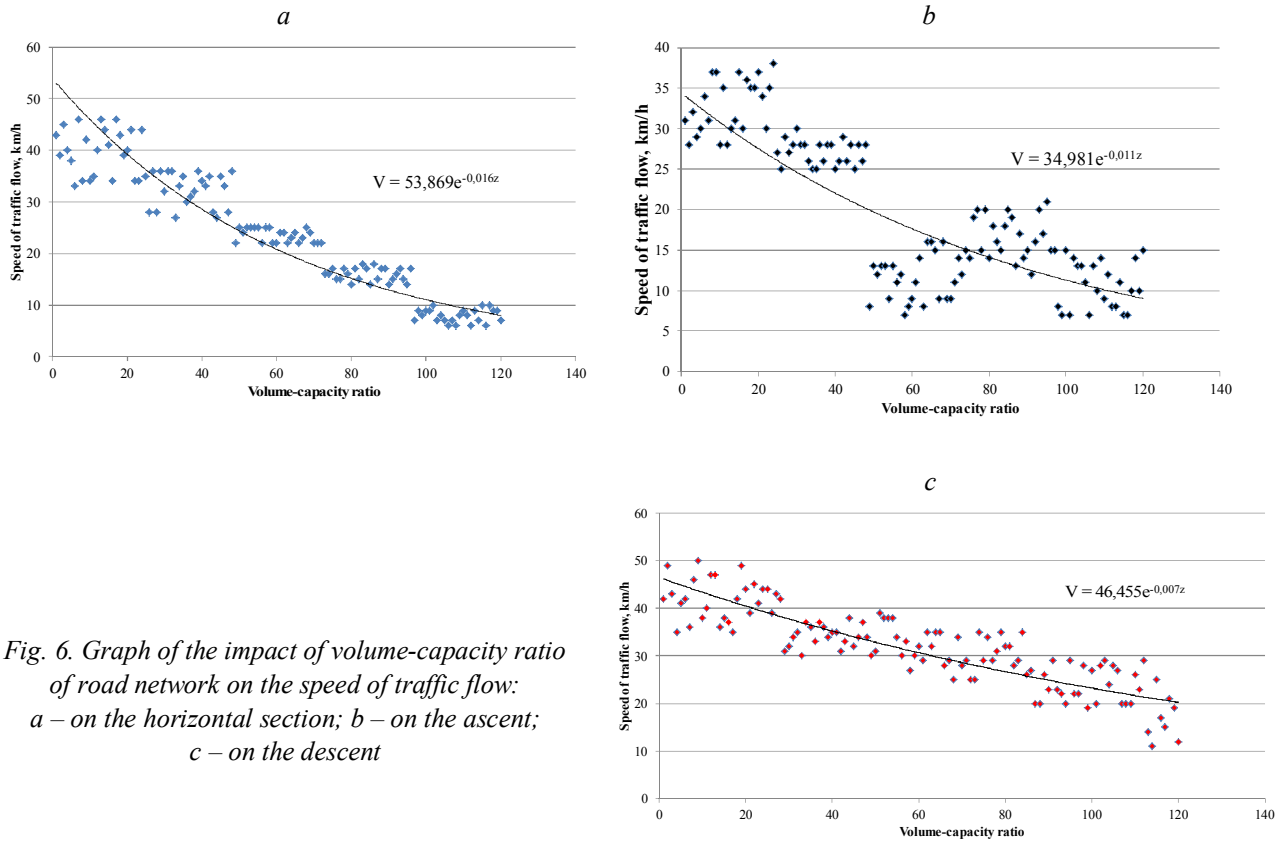

Fig. 6. Graph of the impact of volume-capacity ratio of road network on the speed of traffic flow: a – on the horizontal section; b – on the ascent; c – on the descent

Having analyzed Fig. 6, we can see that at volume-capacity ratio $0< z \leq 0.4$, the traffic flow moves at speed from 35 to 59 km/h in the three studied areas. If we analyze the flow movement on the horizontal section and the descent, we can see that the same structuring of the velocity occurs, but higher values are observed on the descent. During the uphill movement, at volume-capacity ratio $0< z \leq 0.4$, traffic speed is from 24 to 38 km/h, at a higher volume-capacity ratio – 7–22 km/h. It is explained by the fact that groups and packs of cars begin to form at load levels A and B, overtaking stops, and the flow moves in a column at load levels C and D.

Therefore, the analysis of road conditions and their influence on the speed of flows in the city using the derived dependencies showed that the main factors that determine traffic modes are traffic volume and composition, and the presence of ascent (descent).

Traffic simulation was used in the PTV VISSIM software environment to investigate the influence of traffic volume and composition on its average speed. Previous studies show that the speed of the heterogeneous flow has a curvilinear dependence from the volume and composition of the flow. Let us simulate the traffic flow on the horizontal section, ascent and descent according to the given algorithm:

1. A single-lane section (3.75 m wide) with a length of 1,000 m has been created, and there is a horizontal section, ascent and descent.

2. The input traffic flow is given; the actual traffic volume varied from 100 to 800 p.c.u./h. The capacity of the traffic lane was assumed to be 800 p.c.u./h.
3. A homogeneous and heterogeneous traffic flow were created (the share of the heterogeneous flow is 0.8; 0.6; 0.4; 0.2, and 0 % (fully freight and bus flow)). In addition, a corresponding speed value is set for each type of vehicle:
   - for cars – 45 km/h;
   - for freight vehicles – 30 km/h;
   - for buses – 25 km/h.

Traffic simulation of traffic lane operation at different traffic volumes and compositions was carried out to obtain more reliable data. The simulation results for the horizontal section, ascent and descent are shown in Fig. 7.

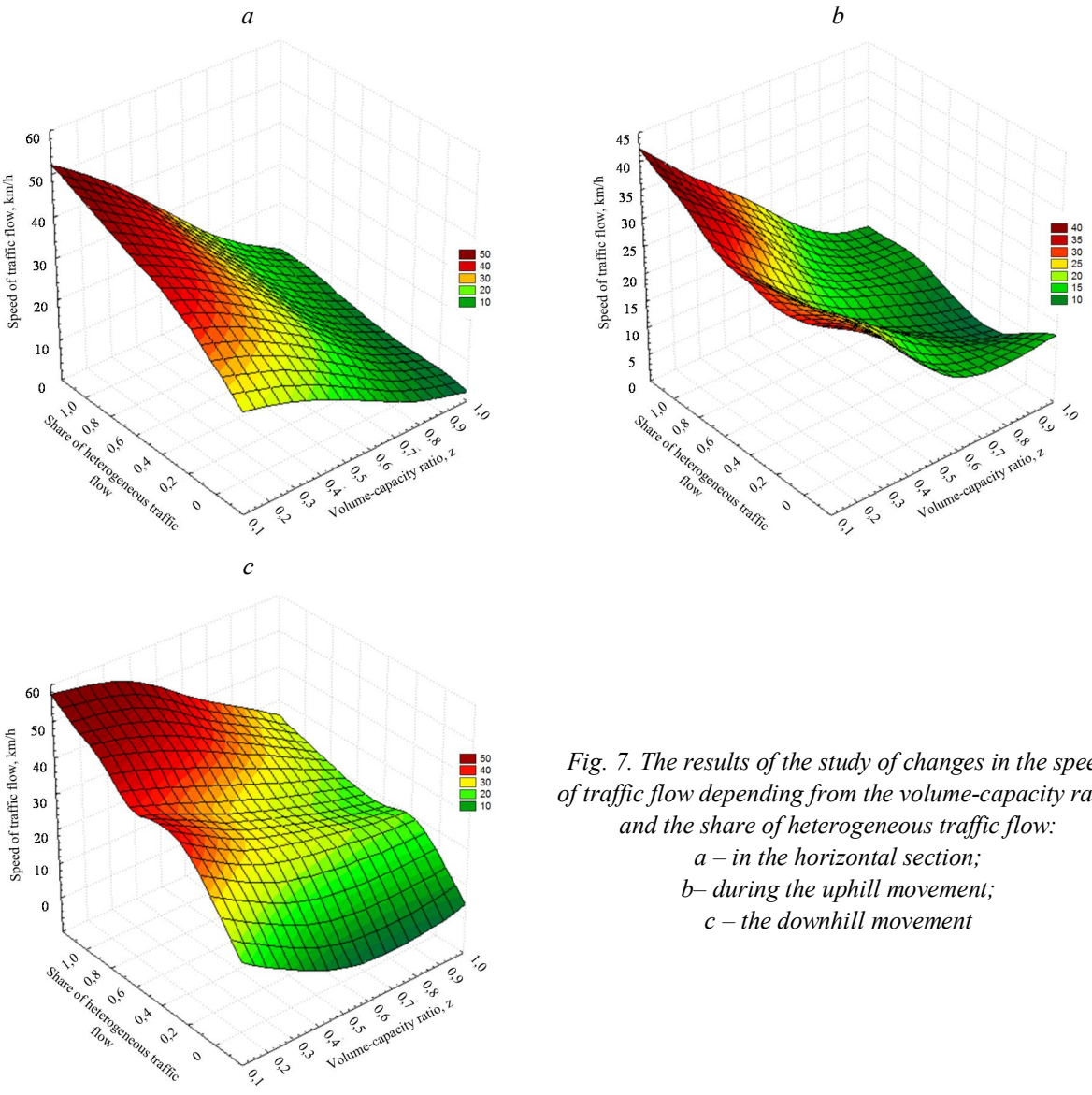

Fig. 7. The results of the study of changes in the speed of traffic flow depending from the volume-capacity ratio and the share of heterogeneous traffic flow: a – in the horizontal section; b– during the uphill movement; c – the downhill movement

Fig. 7 shows how the speed of the traffic flow changes depending on the volume-capacity ratio and the share of the heterogeneous traffic flow using the MATHLAB software environment.

As the results of the simulation of the change in the speed of the traffic flow in the various studied areas show, the highest traffic speed is observed on the descent – 58.62 km/h at the volume-capacity ratio

of the roadway – 0.13 and the share of the heterogeneous traffic flow – 1.0 (100 % cars). If, under the same traffic conditions, the speed of the traffic flow is compared for the horizontal section and on the ascent, we can say that the traffic speed decreases and is 52.63 km/h and 42.1 km/h, respectively. An increase in the volume-capacity ratio of the roadway (z = 0.88) and under the existing traffic conditions (share of heterogeneous traffic flow – 0.8), the speed of the flow on the horizontal section, ascent and descent is 7.2 km/h, 6.3 km/h and 7.5 km/h respectively. Having compared the average value of the speed of the traffic flow on the considered sections, we can say that it (speed) is almost the same (the deviation is 6 % on average). It can be explained by the fact that at the volume-capacity ratio (z = 0.88), the traffic flow is in traffic jam, so the speed of movement in the three sections is the same.

7. CONCLUSIONS AND FUTURE RESEARCH PERSPECTIVES

Therefore, traffic modes obtained by modeling the movement of the traffic flow on a horizontal section, ascent and descent (using the PTV VISSIM and MATHLAB software products) were determined to study the traffic speed at different traffic volumes and compositions. The average traffic speed takes into account the influence of several factors simultaneously. They are the volume-capacity ratio of the roadway, the share of heterogeneous traffic flow, and the length of the section. The conducted studies allow considering the traffic conditions more completely when justifying the estimated speed of the traffic flow. As a result, the capacity of the street-road network increases.

Further scientific research in this direction aims to develop a recommendation for increasing the capacity based on assessing the interaction of traffic and pedestrian flows on a horizontal section, ascent and descent.

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ВПЛИВ ІНТЕНСИВНОСТІ ТА СКЛАДУ ТРАНСПОРТНОГО ПОТОКУ НА ЗМІНУ ЙОГО ШВИДКОСТІ

Анотація. *Досліджено проблематику зміни швидкості транспортного потоку за різної інтенсивності та складу його руху. Для дослідження було обрано ділянку вулично-дорожньої мережі з різними геометричними параметрами (спуск, підйом та горизонтальна ділянка). Проаналізовано методи дослідження швидкості транспортного потоку, а також чинники, які впливають на зниження пропускної здатності вулично-дорожньої мережі. Визначено зміну коефіцієнтів нерівномірності руху транспортних потоків за годинами доби на досліджуваній ділянці та побудовано графік розподілу інтенсивності руху по годинах доби. Побудовано схему ділянки для визначення швидкості транспортного потоку, на якій присутній рух горизонтальною ділянкою, рух на підйом та спуск. Встановлено, що за інтенсивності руху 700–800 од./год транспортний потік рухається зі сталою швидкістю (до 10–15 км/год). Побудовано криві розподілу швидкості потоку, що характеризують режими руху транспортних потоків на вулично-дорожній мережі. Визначено, що якщо рівень завантаження $0< z \leq 0,4$, на трьох досліджуваних ділянках транспортний потік рухається зі швидкістю від 35 км/год до 59 км/год. У програмному спеціалізованому продукті PTV VISSIM розроблено моделювання транспортного потоку на горизонтальній ділянці, підйомі та спуску. З використанням програмного середовища MATHLAB показано, як змінюється швидкість транспортного потоку залежно від рівня завантаження та частки змішаного транспортного потоку. Встановлено, що найбільша швидкість потоку спостерігається під час руху на спуск – 58,62 км/год за рівня завантаження проїзної частини – 0,13 та частки змішаного транспортного потоку – 1,0 (повністю легковий потік). За рівня завантаження проїзної частини ($z = 0,88$) та за існуючих умов руху швидкість потоку на горизонтальній ділянці під часу руху на підйом практично є однакова (відхилення в середньому становить 6 %). Це можна пояснити тим, що за рівня завантаження ($z = 0,88$) транспортний потік перебуває у заторовому стані, відповідно швидкість руху на трьох ділянках є однаковою.*

Ключові слова: *вулично-дорожня мережа, транспортний потік, інтенсивність руху, швидкість руху, пропускна здатність, рівень завантаження, моделювання руху, натурні дослідження, геометричні параметри.*