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# JUSTIFICATION OF THE CRITERIA FOR ALLOCATION OF SEPARATE LANES FOR URBAN PUBLIC TRANSPORT

**Summary.** *The article is devoted to the methodology and research results of traffic flow parameters on the arterial streets, where different regimes of prioritizing urban public transport operate. The regularities of changes of such parameters make it possible to identify and differentiate the sections of transport network in terms of service efficiency, with the aim to implement various regulatory measures that would help to minimize delays in traffic flow. Quantitative and qualitative criteria for ensuring priority transit of urban public transport on different sections of transport network depending on the intensity, speed and composition of traffic, as well as the roadway parameters are defined and substantiated. According to the research outcomes, scientifically based approaches are recommended for the implementation of different schemes of traffic flows control on the sections of the transport network, which differ in planning parameters and of traffic conditions and provide rational transport service based on the criterion of time loss for movement of residents. These results are adequate for large and very large cities with dense construction area.*

**Key words:** *traffic flow, urban public transport, road network, transport network, traffic delay, traffic intensity, speed of movement, traffic flow composition, roadway, route network.*

## 1. INTRODUCTION

For most modern cities, the urgent problem is to ensure the efficient functioning of the transport system (TS), which would ensure fast, high quality and safe movement of residents. It can be accomplished by walking, cycling, driving the vehicle, micrimobility, private vehicles, urban public transport (UPT), or different combinations on one or more routes. The choice of the method of transportation depends on: the size of the city; terrain; functional planning of urban territory and specifics of transport districts location; road network (RN) and transport network (TN) density; configuration and stage of UPT route integration; transport infrastructure development; strategy of sustainable development and urban mobility planning, etc. Based on these parameters, cities are differentiated by groups that have common and distinct characteristics which are reflected through the regularities of transport, pedestrian and passenger flow formation. At this stage, they (cities) are united by one important task – to reduce total time losses from the movement of all groups of residents. Besides, there is a steady increase in the level of urbanization within countries and large territorial complexes, as well as the motorization level that is especially inherent to Ukrainian cities, where, unlike most cities in developed countries, there is a significant indicator of the constant use of a private car when traveling around the city. At the same time, cities do not have capacity reserves, i.e. there is no possibility to increase roadway parameters which could fully meet the demand from private vehicle owners and other road traffic users. Taking into account these tendencies, there is a need to give the priority to one or other road users in different sections of the RN. This prioritization is always a compromise solution which should be based on the principles of rationality and provision of the movement alternatives. By rationality is meant that achieving a solution to a transport problem (for example, reduction of time losses from movement) for one group of road users cannot occur while not completely ignoring the interests of the other groups. It should also be noted that not all cities have easy alternatives in movement as there is a lack of transport infrastructure development. In some cities, mainly "new", infrastructure of which has been formed since the beginning of the 20th century, rapid UPT is developed (subway, urban rail, etc.), modern highways of continuous movement have been designed, and others, RN of which has been formed historically during many centuries, do not have such infrastructure and they are almost unsuitable for service of existing traffic volume. This results in constant traffic jams in the old districts, significant speed reduction on approaches to them and and relatively free peripheral traffic conditions. Partly, these problems are solved by the implementation of automated systems of traffic control, intelligent transport systems elements and improved schemes of traffic organization. However, in historic dense urban cities without prioritizing UPT it is extremely difficult to make mass movement of people.

## 2. RESEARCH STATEMENT

Well-known scientific theoretical approaches to solving the problem of ensuring the effective functioning of urban movement system need constant specification which could be based on the results of mass field research and traffic modeling as regularities in the flows of road users are variable, associated with the increase of their intensity, redistribution by RN territory, the emergence of alternative (to motorized transport) types of transportation. Besides, existent State Building Norms (SBN), governing the arrangement of transport infrastructure, provide for the same approach to design the schemes of traffic organization for all settlements, particularly cities, which is not always an adequate solution as they (cities) differ by type and nature of construction area, functional peculiarities, transportation specifics, RN and TN parameters.

In this research, an accent is made on the justification of criteria for allocation the separate lanes for UPT movement in cities with dense building and ring-radial RN configuration. We assume that for the determined transport, road, and city planning indicators (parameters) in different sections of arterial TN there are traffic conditions under which UPT can move in the general structure of traffic flow, have priority only when passaging the intersections or be provided with priority at the controlled intersections and sections between them.

## 3. RELEVANCE OF THE STUDY

Development of justified criteria for allocation of separate lanes for UPT movement will allow to reduce the overall time lost for moving people through the city and also propose rational alternatives to routes with a combination of different transport modes which, besides time losses, will provide comfort, convenience, and safety. Reduction of the overall delay in traffic flow will contribute to speed equalization, improvement of the effectiveness of automated systems of traffic control operation, decrease of urban air pollution by flue gas emissions and transport noise. Giving the priority to UPT will allow mass transportation by TN as well as create conditions for giving the preference to this transport mode in comparison with private cars. In the worldwide science and practice, such approaches are important components in the development of sustainable urban mobility plans that make special emphasis on the involvement of citizens and stakeholders, coordination between different spheres (transport, land use, ecology, economic development, social policy, health care, etc.).

The development and implementation of sustainable urban mobility plans should not be considered as additional stratification in transport planning but should be carried out in accordance with and on the basis of existing plans and planning processes.

## 4. AIM AND THE TASK OF RESEARCH

The aim of this research is to determine the metrics in the traffic flow on an urban arterial based on its planning features, as well as their system analysis, with further standard-setting criteria to justify the feasibility of allocation segregated lanes for UPT and regulatory measures on controlled sections.

To achieve the aim of the research, the following tasks were formulated:

– to analyze the regularities that appear between traffic flow indicators on the citywide arterial streets of controlled motion during the period of the most intensive motion and the main methods of investigation of these indicators, as well as their connection with the parameters and regimes of traffic light control;

– to determine the main factors that cause delays in the movement of the general traffic flow and vehicles of UPT on different sections of RN;
– to carry out field research to determine a traffic intensity and traffic composition on the lanes that serve mixed traffic and UPT on controlled sections of arterial streets;
– to determine and justify the criteria for the application of different regulatory measures during UPT prioritization deriving from dependencies between movement indicators, and also geometric parameters of TN;
– to elaborate recommendations for the improvement of a regulatory framework that standardize the allocation of separate lanes for UPT movement.

During conducting this research, such methods are applied: field research to determine traffic flow parameters, and also regimes and parameters of traffic light control; system analysis for establishing the relationship between the main factors; mathematical statistics for processing the results of field research; mathematical modeling for construction and description of regularities between traffic flow parameters, and also parameters and regimes of traffic light control.

## 5. ANALYSIS OF RESENT RESEARCH AND PUBLICATIONS

The analysis of the existing scientific researches on the given problems is divided into two parts. In the first part, we will give regulations of the applicable SBN. The standard [1] stipulates that the choice of type of route passenger transport should be made considering the provision of convenient and safe movements of the population and daily pendulum migrants from the adjacent territories, depending on the number of the population and the size of the settlement territory, based on estimated passenger flows, trip distance, the main technical and operational indicators of certain modes of transport, with observance of the normative expenses of time for movement. It is also stated that urban bus and trolleybus lanes should be provided on the arterial streets of citywide and district importance with the organization of traffic in the general flow or in the lane which is specially allocated on the roadway. If we analyze the standard [2], it regulates more precisely the questions of allocation the separate lanes for UPT with indication that on the roadway of the arterial streets and roads special lanes for route transport should be allocated depending on traffic composition, traffic intensity and movement of vehicles, and also the requirements of the road safety by the number of traffic lanes no less than 3 in one direction. It is also stated that in the conditions of reconstruction on the street sections with historical and / or existing building it is allowed to arrange lanes for route vehicles with two lanes in one direction. The drawback or inaccuracy of these standards is that it does not reflect what the composition, intensity and speed of movement should be in order to justify the allocation of a particular lane. Considering arterial TN in the conditions of radial-ring configuration of RN then sections, where traffic flow movement nature corresponds to the criteria of comfort levels A and B [3], and there are no obstacles for UPT movement, can be allocated. Based on this, there will arise a question about the expedience to allocate the lane for UPT movement already at this stage, thus removing it from the general traffic flow, thereby causing its additional saturation, especially in conditions of two-lane one-way directions. In this case, it is necessary to either create so-called park-and-ride parking where there is a possibility to change transportation mode from a private car to UPT or to propose an alternative route for the movement of private vehicles. It is also necessary to take into account the intensity of UPT movement by the section of the arterial TN, and also fullness of its rolling stock. If to consider radial arterial street, then in the direction from the periphery to the center, traffic flow movement conditions become more complicated which is caused by the increase of RN density and appearance of a large number of intersections and pedestrian crosswalks; fraction of local movement in comparison with transit movement; number of UPT routes; intensity of pedestrian and cycling movement, etc. Therefore, regulatory measures should also be different as their task is to improve the transport service for all people who travel. Summarizing the normative part of the analysis, we can assert the ambiguity of the conditions and the lack of strict regulation of criteria about allocation the separate lanes for UPT and the ways of movement control on them. On the one hand, it increases the autonomy for decision-making on the design stage which is a strong side while solving the problem but on the other hand, it does not justify the effectiveness of the measures which is the basis for more detailed scientific research.

The second part of the analysis is based on scientific research carried out by scientists in different countries. We concentrate on those results, which more fully reflect the problem formulated with the aim of the research.

The effectiveness of the functioning of separate lanes for UPT can be evaluated by reducing delays on the routes choosing the way of traffic flow control on TN sections by providing different priorities and simulating the movement of general traffic flow and UPT.

In studies [4–5], under traffic delay means an arbitrary reduction of vehicle speed in comparison with estimated speed for particular street or road section. When assessing the conditions of private transport movement such delay can be caused by the regimes of control at uncontrolled and controlled intersections and pedestrian crosswalks, traffic flow density and intensity as well as by the condition and the type of road pavement. In the case of the UPT, in addition to the above factors, this includes the time losses associated with regulated delays at stopping points.

The authors [6] investigated the main characteristics of traffic flow – intensity, density, and speed in zone of UPT stops operation and their impact on perturbation that appear in traffic flow. It is determined that with the reduction of traffic intensity and speed, the fluctuation of traffic flow in the zone of UPT stop increase.

In the study [7] it is noted that for the use of the existing reserves of road capacity and increase of UPT speed on city streets the complex of engineering, planning, and logistic measures is applied. However, usually, all these measures are insufficiently studied and do not consider the growth of vehicle movement intensity in limited roadway width. In conditions of insufficient RN density and simultaneous growth of vehicle movement intensity, a lot of organizational and technical measures do not allow the organization of duplicate directions for the distribution of private transport and UPT. A significant positive effect of prioritizing UPT is observed if one or more of the following factors are present: long UPT routes; high frequency of UPT movement; low speeds; ineffective distribution of permission signals duration in traffic light control; difficult conditions for arrangement of management by directions on intersections; inappropriate location of UPT stops to the intersection, etc. The authors suggest the following ways of prioritizing UPT at intersections: passive, active, and adaptive. At the same time, it is stated that in each case, it is necessary to carry out detailed study of the main characteristics of traffic flow for the estimation of the effectiveness of measures that are applied in practice.

Similar judgments are outlined in studies [8–9] where such possible priorities for UPT are given: passive or active, and unconditional or conditional. Simulation results upon active conditional priority for UPT show that such priority for buses causes the reduction of time on the route by 6 %, and for the other vehicles, it causes the increase up to 6 % on considered directions and up to 13 % in the conflicting ones. A similar technique for determining the effect from active priority implementation was analyzed in the study [10], where the results showed a reduction of delay by 67.4 % for buses, and the rest traffic flow by 9.2 %. At the same time, in the article [11], a comparison between unconditional and conditional priority is carried out. They both operate on lanes for UPT movement in the conditions of traffic light control with the only difference being that unconditional priority is always given to UPT, and conditional priority is given when UPT is behind schedule. The results obtained highlight the increase of delays up to 40 sec/u during three hours of peak-time research under unconditional priority while movement conditions under conditional priority and without priority are almost the same. After applying the absolute priority in these conditions, above 90 % of buses got zero delays, with a conditional priority received 74 %, and several buses received a delay of more than 30 sec / u. According to the results of passive priority research, namely implementation of “green wave”, summarizes the reduction of the average delay of UPT vehicles by 13.14 sec/u and private transport by 2,22 % in comparison with the traditional model of traffic light cycle optimization under passive priority [12]. The proposed model also allows increasing the passage of private transport through the intersection by 4.45 % in comparison with the traditional model.

Authors [13] highlight the importance of giving the priority to UPT at controlled intersections using automatic vehicle location in traffic flow. The usage of this technology is possible both at the separate isolated intersections and the whole city RN. Herewith, it is noted that the usage of detectors to determine the UPT vehicles location in terms of giving it priority increases the technical speed of rolling stock by 5–16 % and increases the accuracy to schedules by 5–20 %.

Particular attention in conditions of UPT priority should be paid to the principle of control, which is described in the study [14], in which traffic lane is used by the mixed traffic flow in the absence of UPT, and with its appearance, other vehicles, informed by controlled road signs and traffic lights, are obliged to clear the given lane. Here, the achievement of UPT stable velocity is noted upon condition when traffic intensity is 0.70–0.75 out of the capacity. In general, the usage of this principle of control in RN sections can increase the UPT velocity up to 10 % in conditions of intensive traffic flows in comparison with normal routes where there is a mixed use of the lane by general traffic flow and UPT.

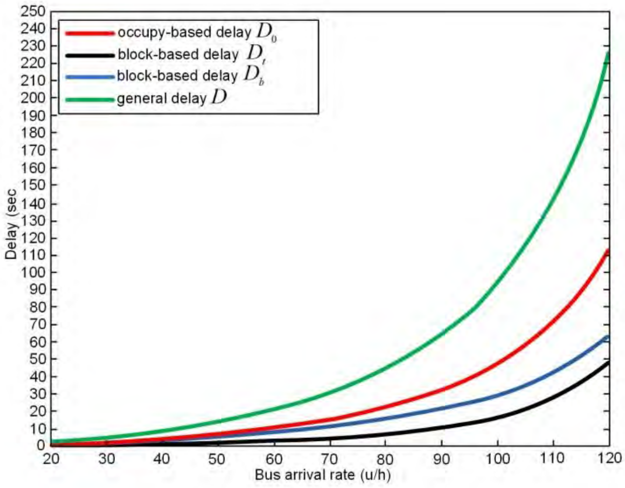
Also, situations of redistribution of lanes between the general flow and UPT are analyzed. In the study [15] the results of simulation on the street in the central part of the city with two-by-two lanes with trams operating in the middle two lanes are given. Parking is permitted on the curbside lanes except at peak times. Traffic volumes are large inbound (1300 veh/h) and outbound (880 veh/h) (left-handed movement). Here, two road situations are simulated. In the first case, the middle lane in the peak period is allocated only for trams, only straight movement is allowed at every second intersection. In the second case, the middle lane in the peak period is also allocated only for trams, but at the intersections, right turns are allowed. The model is developed with existing traffic flow intensity and assuming a 20-percent increase in traffic flows. Results showed that in the base case (general traffic flow is allowed on all lanes), with the increase of the intensity, the time of passage the street will increase by 55 % for trams and by 59 % for the general traffic flow. By simulation results of the first case, the duration of passage will decrease for trams in existing and increased traffic intensity but will increase significantly for the general traffic flow. In the second case, the effect for the general traffic flow will be more negative upon the almost unchanged duration of trams passage.

When analyzing the transport service effectiveness on allocated lanes for UPT, it is also necessary to pay attention to the delays that appear in UPT stops area. Thus, researchers in the study [16] analyzed movement conditions on the street with four-by-four lanes, which serve intensive traffic flows, pedestrian flows, and UPT near the stop. They admit the reduction of the volume-capacity ratio between two stops in conditions of allocation the lane for UPT from 0.86 and 0.97 to 0.61 and 0.62, respectively.

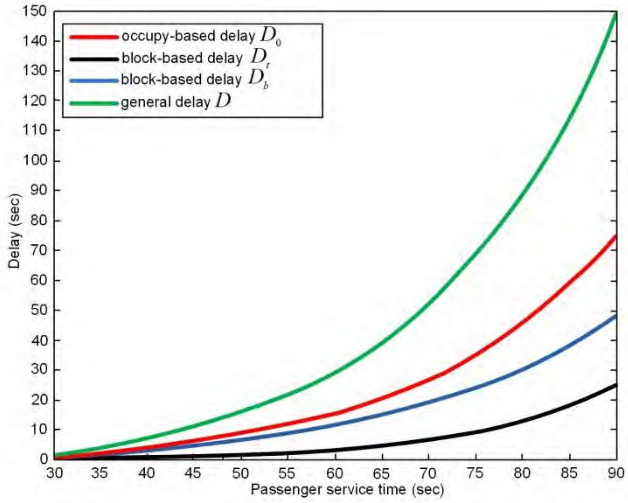
In the article [17], such situations during the simulation the delay on UPT stops before controlled intersections:

– situation A: when bus arriving to the stop all the berths are occupied by other buses that serve passengers. In this case, it has to stay it the queue and wait for entry. Such waiting time is defined as an occupy-based delay $D_0$;
– situation B: the bus has finished passenger serving and intends to exit a stop. But, they are blocked with the vehicles in front and restrictive signal at the intersection, so they have to stay in berth, which makes the bus in the queue continue queuing. In this case, additional waiting time appears, which is defined as a block-based delay $D_t$;
– situation C: the bus has finished passenger serving and intends to exit a stop, but it is blocked with front buses and restrictive signals at the intersection. Waiting time on the exit from the intersection is defined as a block-based delay $D_b$.

General bus delay ($D$) on UPT stop is the average bus waiting time for the entrance, passenger service, and exit. Fig. 1 shows dependence of the UPT delay in the UPT stop zone on the bus arrival rate (*a*) and passenger service time (*b*).




*a*




*b*

*Fig. 1. Change of bus delay in the UPT stop zone depending on their arrival rate and passenger service time [17]*

This theoretical analysis allows defining the main factors that determine the effectiveness of transport service on the sections of city arterial streets where UPT moves, expressed by traffic delay. These factors are: traffic flow intensity, UPT intensity, and intensity of pedestrian flow at uncontrolled pedestrian crosswalks, duration of service on UPT stops, the distance between intersections or pedestrian crosswalks, and the number of lanes in one direction.

## 6. PRESENTATION OF BASIC MATERIAL

Based on the aim and the task of research, the sections of arterial streets in Lviv city where UPT lanes are allocated have been chosen as the objects. They are:

– Chornovola Avenue (toward the center) from the intersection with Khimichna Street to the intersections with Kulisha Street and Pid Dubom Street (section 1; two lanes in one direction);
– Chornovola Avenue (from the center) from the intersections with Kulisha Street and Pid Dubom Street to the intersection with Khimichna Street (section 2; two lanes in one direction);
– Svobody Avenue from the intersection with Horodotska Street to the intersection with Hnatiuka Street (section 3; three lanes in one direction);
– Mytropolyta Andreia Street from the intersection with Bandery, Antonovycha, and Rusovykh Streets to Sviatoho Yura Square (section 4; two lanes in one direction);
– Mytropolyta Andreia Street from the intersection with Sviatoho Yura Square to the intersection with Bandery, Antonovycha, and Rusovykh Streets (section 5; two lanes in one direction);
– Horodotska Street from the intersection with Chernivetska Street to the intersection with Kulparkivska Street (section 6; three lanes in one direction);
– Horodotska Street from the intersection with Kulparkivska Street to the intersection with Chernivetska Street (section 7; two lanes in one direction).

The investigated sections are in different functional zones of the city which are distinguished by the peculiarities of transport service, UPT share, geometric parameters (the length of allocated lanes and the density of TN and RN), and the regulation is carried out by traffic light control with the fixed-time algorithm. These aspects are important during the identification of characteristic regularities of transport service. During the field research, an important task was to measure the intensity and velocity of UPT and compare their values with the lanes where general traffic flow moves. General peculiarities of movement on the investigated objects are:

- violation of the rules of traffic by drivers of private vehicles in conditions when before the stop-line a queue of vehicles appears in the lane that serves the general traffic flow;
- the difficulty of the right turn maneuver of the general traffic flow through the allocated lanes with significant UPT intensity;
- absence of parking restriction.

For the measurement of traffic flow indicators, the operative flow account was applied, which is one of the subtypes of the field research. To receive adequate results and their further analysis, it is necessary to carry out such a sequence of actions:

- measurements should be carried out in peak periods or periods of the most intensive motion on weekdays;
- minimal sample size (n) for every measurement of instantaneous velocity should be 50 vehicles that pass the experimental section;
- during the measurements, it is necessary to record the type of vehicle and also time spent on the passage of street section between stop-lines (for UPT, if such stop-line is absent, time of passage between UPT stops should be recorded) or control points (measurement base);
- to obtain regularities between traffic flow indicators, actual intensity should be converted to passenger car equivalent intensity, using appropriate coefficients for urban conditions;
- using mathematical statistics methods, it is necessary to calculate the average instantaneous velocity separately for mixed-use lanes and allocated UPT lanes

The results of field research are given in Table 1.

*Table 1*

**Results of investigation of traffic flow intensity, velocity, and composition on sections of arterial streets with allocated UPT lanes**

| Research object with lane indication | Actual traffic intensity on the lane, auto/15 min | | | | Passenger car equivalent intensity on the lane, pcu/15 min | Average velocity on the lane, km/h | Traffic flow composition on the lane, % | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | C | T | B | Tr | | | C | T | B | Tr |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Section 1, right lane* | 11 | – | 36 | 3 | 83 | 24.4 | 22 | – | 72 | 6 |
| Section 1, left lane | 47 | 2 | 1 | – | 56.3 | 24.5 | 94 | 4 | 2 | 0 |
| Section 2, right lane* | 9 | 2 | 38 | 1 | 82.2 | 22.6 | 18 | 4 | 76 | 2 |
| Section 2, left lane | 50 | – | – | – | 50 | 11.5 | 100 | – | – | – |
| Section 3, right lane* | 18 | 3 | 29 | – | 74.7 | 23.2 | 36 | 6 | 58 | – |
| Section 3, middle lane | 40 | 4 | 4 | 2 | 58 | 23.5 | 80 | 8 | 8 | 4 |
| Section 3, left lane | 40 | 5 | 4 | 1 | 61.1 | 22.4 | 80 | 10 | 8 | 2 |
| Section 4, right lane* | 8 | – | 30 | 12 | 90.8 | 39.6 | 16 | – | 60 | 24 |

*Table continuation 1*

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|
| Section 4, left lane | 44 | 5 | 1 | – | 56.3 | 25.9 | 88 | 10 | 2 | – |
| Section 5, left lane | 36 | 3 | 6 | 5 | 63.3 | 38.3 | 72 | 6 | 12 | 10 |
| Section 6, right lane* | – | – | 47 | 3 | 91.8 | 18.4 | – | – | 94 | 6 |
| Section 6, middle lane | 48 | 2 | – | – | 51 | 19.7 | 96 | 4 | – | – |
| Section 6, left lane | 42 | 6 | 2 | – | 54.8 | 19 | 84 | 12 | 4 | – |
| Section 7, right lane* | 40 | 4 | 5 | 1 | 57.4 | 18.7 | 80 | 8 | 10 | 2 |
| Section 7, left lane | 43 | 3 | 4 | – | 54.7 | 18.9 | 86 | 6 | 8 | – |

*Note. Lane only for UPT

Graphic interpretation of research results, given in Table 1, filed in the form of Fig. 2.

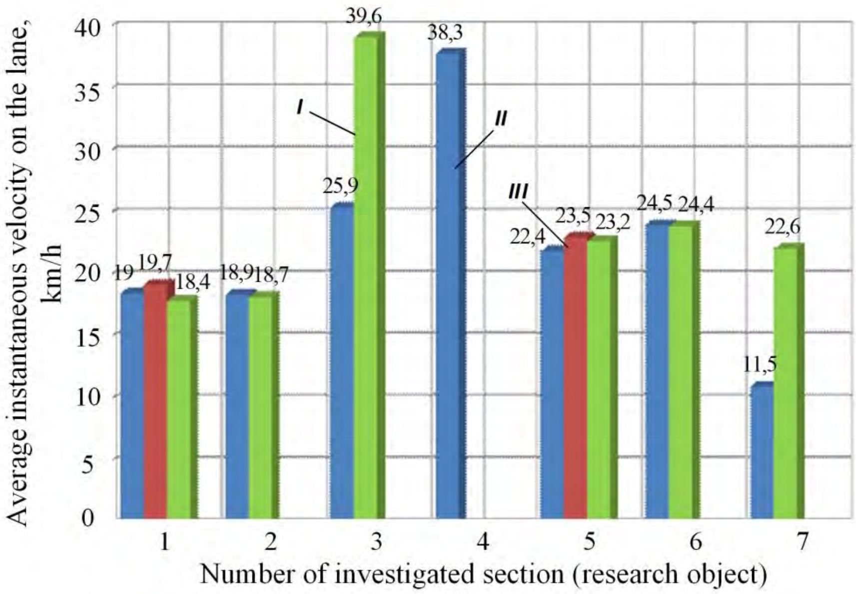



*Fig. 2. Results of calculation of the average instantaneous velocity on sections of arterial streets with allocated UPT lanes: 1 – section 6 (Horodotska Street); 2 – section 7 (Horodotska Street); 3 – section 4 (Mytropolyta Andreia Street); 4 – section 5 (Mytropolyta Andreia Street); 5 – section 3 (Svobody Avenue); 6 – section 1 (Chornovola Avenue); 7 – section 2 (Chornovola Avenue); I – UPT lane; II (III) – left (middle) lane for mixed traffic*

In Table 1, actual and passenger car equivalent intensity are given as the average value according to the results of 20 measurements in the peak period, the duration of which was 15 min. The intensity of UPT movement is significant in almost all investigated sections (about 160 buses and trolleybuses during the hour), which is explained by laying on them many UPT routes. The greatest effect was achieved because of the UPT lane allocation on the experimental sections 4 (Mytropolyta Andreia Street) and 7 (Chornovola Avenue), where the difference in velocity values in mixed-use lanes and UPT lanes is 97 % and 53 %. On the experimental section 5, UPT is not allocated, but the field research is carried out with the aim to determine a traffic flow velocity with the large share of UPT. At the same time, on the other experimental sections, as can be seen from Fig. 2, significant effect from UPT lane allocation is not found. It is related, first of all with a significant intensity of buses and trolleybuses as well as a short distance between adjacent intersections or pedestrian crosswalks. If there is a high intensity on the street section in mixed-use lane, then UPT vehicles cannot leave their lane in the UPT stop zone even in the case when they have served passengers. Besides, UPT stops are often allocated before stop-lines at the controlled intersections and pedestrian crosswalks that, as admitted in the literature overview, create an additional delay. Here, we also receive a connection between the length of the assumed section and the speed of movement. In conditions of absence of UPT priority, as in the case of investigated sections of arterial streets and a small distance between intersections (pedestrian crosswalks), to achieve a significant increase in velocity is quite hard. We note that we are talking about instantaneous velocity that was measured in the middle of the section (the street section between stop-lines). If to consider also time spent on boarding-alighting passengers, downtime on the end UPT stops, and time losses, related to traffic light operation regime, then the average technical and operational speed was far smaller.

Based on the results of this research, we could build dependencies of the change of the average instantaneous velocity of UPT movement on the allocated lanes on their intensity (Fig. 3) and section length (Fig. 4).

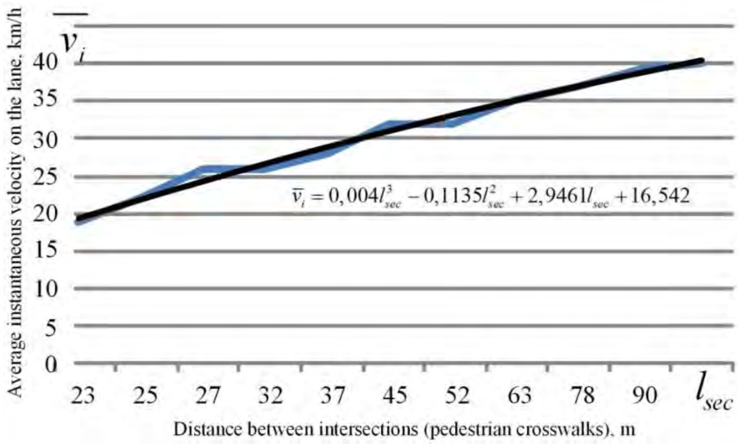



*Fig. 3. Change of the average instantaneous velocity of UPT vehicles on allocated lane depending on the section length (distances between adjacent intersections or pedestrian crosswalks)*

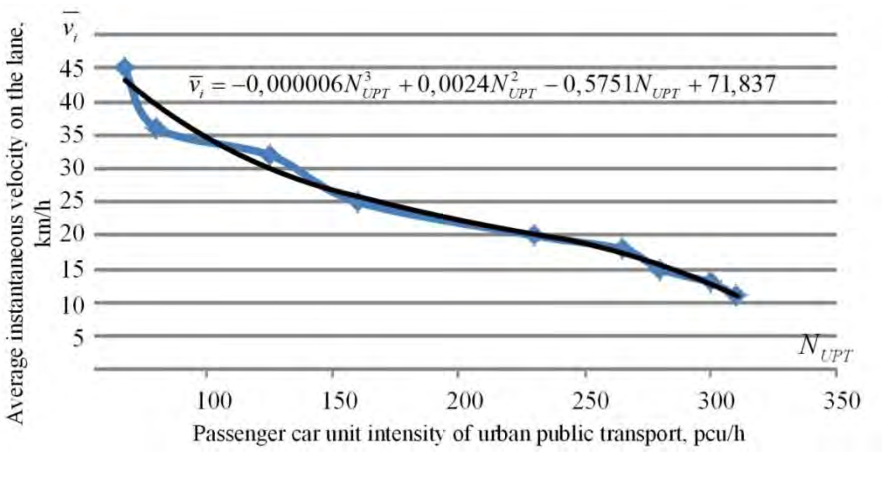



*Fig. 4. Change of the average instantaneous velocity of UPT vehicles on allocated lane depending on the buses and trolleybuses intensity*

Having analyzed Fig. 3, we can state that there is a direct dependence between the average instantaneous velocity and section length. The increase of distance between adjacent controlled intersections or UPT stops, or pedestrian crosswalks within approximate limits 20–100 m gives the increase of the average instantaneous velocity by 20–40 km/h. After the value of 40 km/h, the average instantaneous velocity stabilizes that is related to the regulated location of UPT stops and the technological process of transportation.

From the Fig. 4, it can be affirmed that there is inverse dependence between the average instantaneous velocity and UPT intensity, by which it is found that with the increase of intensity in limits of 75–325 pcu/h is the reduction of the average instantaneous velocity on the allocated lanes from 42 km/h to 15 km/h.

In general, the indicator of the average instantaneous velocity on allocated UPT lanes and general traffic flow is an important factor that justifies the allocation of such lanes. If the increase of UPT speed in comparison with mixed-use lanes can be reached, then such a solution is appropriate. If this increase cannot be reached, then it is necessary to change the traffic organization scheme or to implement different schemes of UPT priority.

## 7. CONCLUSIONS AND FUTURE RESEARCH PERSPECTIVES

Based on the results of this scientific research, the following general conclusions can be made:

a) the main factors that determine a delay in UPT vehicles movement on arterial streets are: traffic intensity, traffic flow composition, the distance between intersection (pedestrian crosswalks) or UPT stops, TN and RN density, the method of traffic management at the controlled intersections (pedestrian crosswalks);
b) the most optimal average instantaneous velocities on allocated UPT lanes are at the traffic intensity above 300 pcu/h per one lane and the share of UPT in it above 20%, and also distances between stop-lines above 100 m;
c) the decrease of the average instantaneous velocity is at the UPT vehicles intensity above 150 pcu/h, which is connected with downtime while waiting for the approach to UPT stop, and also controlled intersection (pedestrian crosswalk) passage, which reduces the effect from the achievement of the difference between UPT vehicles and general traffic flow vehicles;
d) in conditions of transport service that responds to the comfort level A and partly the comfort level B, to allocate UPT lanes is inappropriate; at the lower limit of comfort level B and partly at comfort level C, it is recommended to give passive or active priority for UPT vehicles before intersections; at the lower limit of criteria of comfort level C and the comfort level D, the feasibility of UPT lane allocation is confirmed;
e) the normative documents provide the strict regulation of traffic flow indicators, upon which the expediency of UPT lanes allocation at different TN parameters is justified, as well as the criteria for accomplishing the regulatory measures of priority when implementing the algorithms of traffic light signalization control.

Further research to solve the formulated problem is:

– conducting the field research and increasing the volumes of statistical samples;
– application of specialized software products for conducting simulation to determine the forecasted traffic flow state in future periods;
– systematization of criteria of traffic flow control for different city territories, based on the study of regularities in them to achieve the rapid, comfortable and safe transportation of people;
– development of recommendations about the specification of regulation the UPT stop location to intersections, based on transport service comfort and traffic flow delay minimization;
– determination of the impact of human factor on the choice of the rational way of travel within the city, based on the complex of possible alternatives that are grounded on the principles of intermodality and multimodality;

– achieving sustainable development of the city transport system, which is based on the reduction of exhaust fumes and transport noise.

An important condition for the achievement of such aims is considering the modern scientific tendencies and practical approaches in such branches and directions as urban planning, road construction and infrastructure, informatization and development of artificial intelligence systems, automotive industry, etc.

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