There are different configurations of street and road networks in cities, which is why those transportation models that determine how effectively a public transport network is operated are different. Along with this, some transport areas may have characteristic features predetermined by the density of a street network, the intensity of individual and public traffic. The special feature of the current study is determining the operational effectiveness of dedicated lanes for public transport given a significant density of the main street and road network. Significant density is characterized by its value for the distance between adjacent intersections in the range of 150–200 m. With such planning patterns, there is a mutual influence of the conditions of individual and public transport between adjacent intersections. An increase in the distance between intersections disrupts the stability of traffic flow through its disintegration into separate groups based on the dynamic characteristics of vehicles.

A characteristic feature of the proposed procedure for evaluating the operational effectiveness of dedicated lanes is that the use of a GPS monitoring system makes it possible to relatively quickly determine the areas of the network where there are the greatest delays in movement in real time. After that, attention is focused on investigating the main factors of influence and their parameters followed by modeling.

The reported results would in the future contribute to devising a clear sequence of transport-related research based on a set of their methods in order to acquire representative data and define adequate patterns. An important practical result is the use of not only established normative approaches to the design of dedicated lanes, which are common for all types of street and road networks but taking into consideration the peculiarities characteristic of their individual sections

Keywords: traffic flow, public transport, individual transport, traffic priority, traffic intensity, delay, street and road network

UDC 656.13
DOI: 10.15587/1729-4061.2021.225397

IMPROVEMENT OF METHODS FOR ASSESSING THE EFFECTIVENESS OF DEDICATED LANES FOR PUBLIC TRANSPORT

Ye. Fornalchyk
Doctor of Technical Sciences, Professor*
E-mail: yevgen.fornaltchyk@gmail.com
I. Vikovych
Doctor of Technical Sciences, Professor*
E-mail: ihor.a.vikovych@lpnu.ua
Yu. Royko
PhD, Associate Professor*
E-mail: jurij.rojko@gmail.com
O. Hrytsun
PhD*
E-mail: oleggrutsyn1993@gmail.com
*Department of Transport Technologies
Lviv Polytechnic National University
S. Bandery str., 12, Lviv, Ukraine, 79013

Received date 10.12.2020
Accepted date 02.02.2021
Published date 26.02.2021

1. Introduction

Given a constant increase in traffic volumes and restrictions arising from land use in cities, most streets face significant problems related to traffic flows (congestion, accidents, and gas pollution). They are especially critical in cities with dense infrastructure where street and road network configuration was historically developed.

Congestion causes significant time spent on the movement of people and goods, which makes the city's transport system inefficient. Even though it cannot be eliminated, such congestion can be reduced in two typical engineering ways – increasing the number of lanes and introducing (improving) automated traffic management systems. The first technique is usually difficult to implement due to the lack (or absence) of free territories in a city, as well as due to the high cost of land. Therefore, scientists and engineers focused on the implementation of various organizational measures. For example, improving the methods of urban traffic management by prioritizing certain types of movements; designing sustainable urban mobility plans, and others. The first of the proposed measures is based on that in certain streets traffic preferences are given to one of the groups of road users. Among them, the main (in terms of a share in urban mobility) are users of individual transport, public transport passengers, and pedestrians. The second measure takes into consideration rational approaches to the development of urban territory, based on the criteria for achieving high ease of displacement, minimum economic costs, and less environmental impact. The development of information technologies makes it possible to implement various elements of intelligent control in order to improve the efficiency of interaction between users of the transport network.

World science provides a large body of research into improving the efficiency of passenger transportation in cities by giving ground public transport priority when passing sections of the transport network. Such a priority can be implemented through the allocation of individual streets, dedicated lanes on main streets, ensuring stop-less passage of intersections, etc. The choice of prioritization technique depends on the planning characteristics of streets and intersections, the intensity of traffic. This should include passenger flows along routes, functional zoning, as well as the configuration of street-road and transport networks.

No less important task is to increase traffic safety, as with the increase in traffic intensity caused by the increase in the level of motorization and automotive use, and the lack of development of transport infrastructure, the number of traffic accidents grows. Therefore, those areas of research are relevant whose results would make it possible to determine in detail the prerequisites, algorithm, and consequences of the prioritization of public transport along the sections of the main street-road network with significant density.

2. Literature review and problem statement

Studies [1–3] assess the impact of dedicated bus lanes on urban traffic under conditions of congestion. Specifically, article [1] argues about the possibility of promoting public transport by prioritizing it on all routes. Work [2] compares three scenarios for public transport – traffic within the general traffic flow, the addition of a separate lane nearing the intersection, and the arrangement of a dedicated lane along a large length of the route. Along with that, the authors developed a microscopic transport model along a section of the street 1,000 m long. At such a distance between the intersections, the parameters of the incoming and outgoing traffic flow in this area may have significant differences. In addition, based on the organization of the technological process of transportation, there should be at least one stopping point of public transport within the specified distance, which has a significant impact on the efficiency of the dedicated lane. The results reported in [3] established that the greatest effect of the introduction of dedicated lanes could be achieved if the entire public transport network had been arranged according to that principle. Then there is a general network effect while the indicator of public transport operation during peak periods is identical to non-peak hours. In addition, the acceleration of bus traffic makes them a more attractive way of moving and significantly reduces the share of those users of the transport system who use private cars. At the same time, when considering the network effect, there are no defined efficiency criteria for justifying the implementation of dedicated lanes for different (geometrically) sections of streets.

Quite often, the justification for the effectiveness of dedicated lanes for public transport is based on comparing its delays, as well as delays in the general traffic flow. However, not in terms of the number of vehicles but from the standpoint of transport network users. Thus, work [4] reports the results of a study on the use of simulation modeling and full-scale measurements. The simulation implied the creation of service channels (dedicated lanes highlighted by markings) for public and individual transport. It was determined that the effectiveness of the dedicated lane is justified when using large-capacity buses at the intensity of more than 120 units per hour and at the number of passengers exceeding 40 people in each. In other cases, it is impractical to dedicate a lane throughout the run; it is necessary to solve issues related to priority only close to the intersections. Paper [5] considers the arrangement of a bus lane by reducing the number of lanes for the general traffic flow, from 3 to 2, between two stop lines, the distance between which varied (during the simulation) from 25 m to 125 m. Such a simulation of the model showed that the increase in the total delay (for the entire traffic flow, except public) was from 130 to 430 hours. At the same time, the overall delays of public transport decreased from 50 hours to about 6 hours. However, there remains an unresolved issue related to the mutual influence of public transport rolling stock indicators on the operational efficiency of dedicated lanes.

Special attention should be paid to works [6–8] that consider urban highways with a high level of transit. Thus, paper [6] applied the microscopic simulation model Paramix to model a regional road network in order to assess the effect of road traffic by comparing the speeds of individual transport and buses that move in dedicated lanes. The advantage of this modeling method is not to determine delays in the movement of vehicles before intersections but the average speed of movement as an indicator of changes in road conditions and transportation service conditions. Paper [7] also considers a procedure based on comparing the speeds of buses in the presence and absence of a dedicated lane in the city main street at the actual low traffic intensity and at its increase by 20 %. Additionally, the time for boarding and disembarking of passengers at each stopping point, which is accepted equal to 30 s. Based on the data acquired, it was concluded that the arrangement of a dedicated lane for public transport in the main street almost does not change the average speed of buses while the speed of individual transport reduces by 10 %. This phenomenon can be explained by the fact that buses follow established schedules and they have regulated stops for boarding and disembarking passengers. Therefore, their speed is always less than the speed of individual transport. The allocation of individual lanes for buses in such areas can often be justified either by the significant intensity of their movement on the line (several routes are superimposed) or for traffic safety reasons. Work [8] focuses on public transport services when using algorithms for randomly searching for vehicles (buses) in the flow. The application of such algorithms is based on data acquired from transport detectors that identify that a bus is approaching an intersection. The principle of operation is that the distance between the detector and stop line should be at a distance that the bus can overcome in 7–9 s, which makes it possible for the traffic light to change the group of signals along this direction. In such a control system, it is important to set limits on the minimum and maximum duration of the prohibition signal. The minimum is set in order not to create delays in the direction where there is the intensive movement of public transport and the maximum – for the necessary passage of vehicles and pedestrians moving in adjacent phases of regulation.

The main task of the analyzed methods that justify the arrangement of the dedicated lane for public transport on sections of main streets is to determine the conditions or criteria, based on the comparison of the time spent on movement by public and individual transport.

Another group of researchers argues that the most important task is to provide priority for public transport at intersections as this is where the biggest traffic delays occur. Work [9] focuses on modeling the movement of buses in dedicated lanes between stopping points at different lengths of lanes. The special feature of the cited work is that the movement of low-intensity buses is taken into consideration in a dedicated lane. Given such conditions, the rationale for prioritizing public transport in this way is quite problematic. Paper [10] investigated the prioritized public transport at its considerable intensity by arranging dedicated lanes that are physically separated from the flow of individual transport. The advantage of this solution is to increase the speed of bus service at intersections; at the same time, there are greater issues related to individual transport maneuvers and pedestrian safety. Works [11, 12] provide a broad classification of techniques for the prioritization of public transport at intersections in two directions. In the first technique, there is an active and passive priority. An active priority is to identify and give preference to driving in the direction in which a bus or other public transport vehicle approaches. Passive – when the duration of the phase in the direction that serves public transport is constantly increased. The second technique considers a full, partial, and relative priority. With full priority, they try to achieve zero delays for public transport. At partial – they imply the continuation of the green signal or the early green signal is activated. The relative priority takes into consideration all public transport vehicles approaching an intersection with preference given to those carrying more passengers. The third technique involves unconditional and conditional priority. The difference between them lies in the fact that in the first case, each vehicle of public transport is given priority, and in the second – only to those that lag behind the established traffic schedule. In study [12], the author focuses on conditional priority. He outlines a procedure for managing traffic lights according to the criterion of minimizing time losses and indicates the need to improve the communication system in order to comply with traffic schedules. When analyzing prioritization methods, it is important to note that the necessary monitoring of the number of passengers in the city public transport system can be executed through the electronic ticketing system. This is the case where one can argue about ensuring the passage of more users of transport – people, rather than vehicles.

Another approach is outlined in studies [13, 14] whose authors consider the case of the arrangement of dedicated lanes at the intersection in the case when public transport is served from all its approaches. The emphasis is on the use of simulation by employing the specialized PTV VISSIM programming environment. Priority is given to public transport by using an algorithm based on a special phase activation. That makes it possible to reduce the average bus delay by 50–87 % compared to non-priority adaptive control at intersections where there are no more than two lanes of traffic in each direction. It should be noted that such algorithms are effective during the accidental arrival of buses (trolleybuses or trams) to the intersection at a low intensity from all approaches. Otherwise, it is necessary to execute strict control over the traffic lights.

In order to qualitatively assess the effectiveness of the dedicated lanes for public transport, it is worth paying attention to stopping points where there may also be significant delays in rolling stock. Thus, study [15] identified the components of such a delay associated with the duration of movement to the stop (9–11 seconds), the duration of boarding and disembarking of passengers (7–23 seconds), the duration of departure from the stopping point (5–8 seconds). All these operations depend on the intensity of public transport, the technique a stopping point is arranged, and its location relative to the intersection. At the same time, such delays at stopping points require detailed study in the area of operation of transport and transfer hubs where there is a high coefficient of passenger turnover.

The efficiency and reliability of the transport system must be evaluated or analyzed according to traffic safety indicators. The general issues and analysis of these indicators under the conditions of priority bus transportation are considered in [16] whose authors describe the positive and negative consequences of using various technical means and engineering measures in different countries. It is believed that a detailed analysis of traffic safety in the public transport system should be based on a significant amount of statistics.

Given this, it can be argued that most researchers focus on analyzing the conditions of transport services based on their three main components: the sections of streets between intersections, intersections themselves, as well as stopping points. Each of these components has its characteristics, which are associated with the time over which public transport utilizes it. This is due to the peculiarity of traffic flows, the way of traffic control, and the technological processes of transportation.

Summing up, we emphasize the importance of comprehensive consideration of all the listed factors, methods, and techniques for each public transport route. In addition, it is necessary to justify the arrangement of dedicated lanes in order to ensure rational time spent on the movement around a city by various groups of users of the transport network.

3. The aim and objectives of the study

The aim of this study is to improve a method of evaluating the operational effectiveness of dedicated lanes for public transport depending on the indicators of traffic flows along the sections of a street and road network with significant density.

To achieve the set aim, the following tasks have been solved:

– to conduct transport research to determine the patterns of changing the characteristics of individual and public transport in the sections of main streets with a significant density of street and road network;

– to perform the simulation of the state of a traffic flow along a street's section in the absence and availability of dedicated lanes for public transport.

4. Methods of transport research to determine the indicators of traffic flows with a significant share of public transport

4. 1. Procedure to experimentally determine the indicators of individual and public transport traffic

We have experimentally determined the indicators of individual transport movement according to the procedure of local measurements; for public transport – local and zonal. The main primary indicators studied in our work were speed (average instantaneous, connection speed) and traffic intensity, as well as the composition of traffic flow.

The local measurements of the speed, intensity, and composition of traffic were carried out along a section of the street between intersections. The procedure of local speed measurement was based on the registration of vehicles in the flow, taking into consideration the relevant reservations. In particular, when acquiring the instantaneous speed indicator value for the approaching group, it was necessary to constantly vary the position of the vehicle in it. That is, to avoid taking into consideration only «fast» or only «slow». The number of vehicles (sample size) was recorded, based on types, which should be closely proportional to their share in the traffic flow. If dedicated lanes were arranged for public transport, the speed on the lanes for individual and public transport was separately measured. At the same time, video recording was used while collecting information on all the specified indicators of traffic flow. That makes it possible to improve the accuracy of building experimental dependences.

The primary task of experimental measurement is to determine the number of measurements. It was calculated using a confidence probability function. Since local measurements were carried out on main streets with a significant traffic intensity, when traffic flows were in a state of constant saturation, 12 measurements were carried out for one section of such a street to determine the intensity of traffic. In addition, local measurements of indicators in traffic flows were carried out during peak periods of working days in order to determine their critical values. To determine the representative values of the motion speed, each measurement registered 50 vehicles. The arrays of collected data were treated using the methods of mathematical statistics, taking into consideration the frequency of appearance of the corresponding values of intensity and motion speed. These methods determined the indicators of the distribution of random values (indicators of traffic flow) and its nature. For a traffic flow that is in a state of saturation, its indicators are subject to the normal law of distribution.

For public transport, zonal motion speed measurements were also carried out using the specialized software to monitor movements, MicroGIS (Ukraine), which monitors the movement of GPS sensors located in rolling stock. Information is first generated in the form of «stadiums» of movement (Fig. 1); it can be obtained later in a decrypted form, as given in Table 1.

Having data on the average delay of public transport at the stopping point, the distance between the stopping points and, based on the results of GPS monitoring (Table 1), one can accurately calculate the speed of connection along the sections of the route. In addition, those sections where the lag from the schedule are typical and are constantly found in all reports make it possible to justify decisions to prioritize public transport.

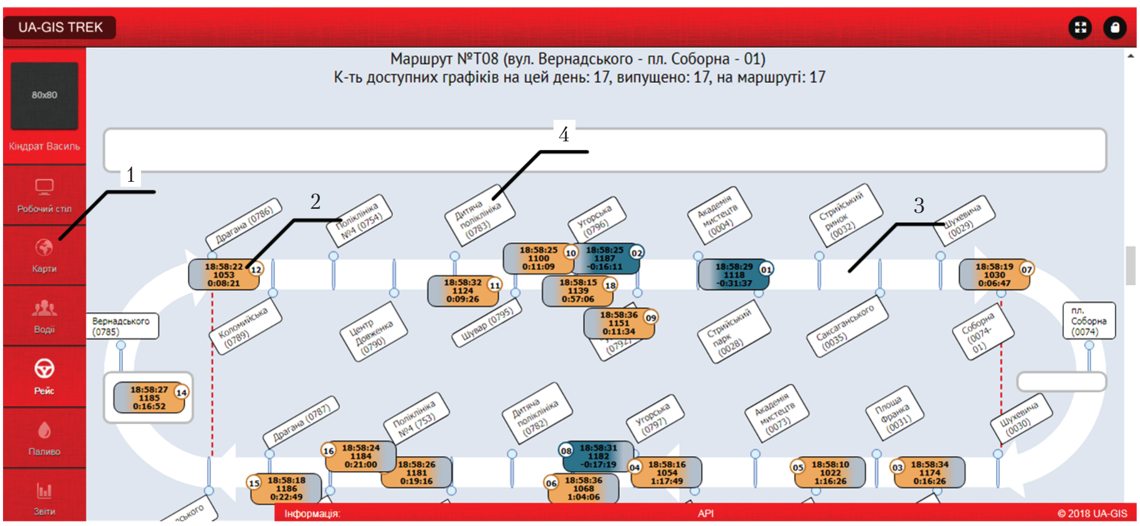

Fig. 1. MicroGIS software interface:
1 – instrument panel; 2 – vehicle indicating the body number and lag time (ahead) relative to the established schedule; 3 – «stadium» of movement; 4 – the name of the stopping point at the «stadium» indicating its citywide code

Table 1

Report from the MicroGIS software on compliance with traffic schedules on a public transport route

Vehicle: AA-6381-TX			
Route A01 (Halyts'ke perekhrestya – Halytska square) 2019/09/01 07:00			
Schedule: 01-4			
Geo-zone (name of the stopping point and its city number)	Planned arrival time at the stopping point	The actual time of arrival at the stopping point	Notes
Halyts'ke perekhrestya, boarding (593)	2019/09/01 10:30	2019/09/01 10:35	Lag behind schedule
Nazaruka (592)	2019/09/01 10:32	2019/09/01 10:39	Lag behind schedule
Skeyt-park (738)	2019/09/01 10:34	2019/09/01 10:39	Lag behind schedule
Avtostantsiya 2 (601)	2019/09/01 10:37	2019/09/01 10:41	Lag behind schedule
....	....	....	....
Khimichna (608)	2019/09/01 10:51	2019/09/01 10:52	Timely arrival
Kulisha (6)	2019/09/01 10:54	2019/09/01 10:53	Timely arrival
Teatr opery ta baletu (68)	2019/09/01 10:58	2019/09/01 10:57	Timely arrival
....	....	....	....
Teatral'na (40)	2019/09/01 11:43	2019/09/01 11:13	Ahead of schedule
Chornovola (7) PK	2019/09/01 11:47	2019/09/01 11:22	Ahead of schedule
PK Khotkevycha (615)	2019/09/01 11:49	2019/09/01 11:23	Ahead of schedule
....	....	....	....
Halyts'ke perekhrestya, disembarking (595)	2019/09/01 12:06	2019/09/01 11:37	Ahead of schedule

Zonal measurements of the movement speed of public transport were carried out constantly, that is, for all the time of rolling stock on routes. That makes it possible to compare the speed values obtained from the results of zonal and local measurements. Additionally, this method of continuous measurement makes it possible to determine the speed of public transport along the sections of the route during the decline in the intensity of individual transport. In order to establish its weighted average value, we treated the data on speed acquired from the results of zonal measurements using mathematical statistics methods.

4. 2. The procedure of research involving the simulation in the PTV VISSIM programming environment

The advantage of simulation using the PTV VISSIM programming environment is the possibility of deriving adequate patterns of change in the state of a traffic flow at its various indicators. Based on the purpose and goals of this study, an algorithm was developed for building a basic model of two-way directions on main streets with the same runs to regulated intersections. This basic model assumes the simulation of the state of a traffic flow in the absence and availability of dedicated lanes for public transport by using the results of field observations.

In the first stage, we calibrated the map with a reference to actual objects of research – the sections of streets. Next, a basic model was built in the following sequence:

– segments with two lanes are accepted that approach the regulated intersection with a length of 200 m;

– a model of each type of vehicle moving in the traffic flow is set indicating their percentage;

– the main control point (stop line) is accepted, which registers the number of vehicles that crossed it in the model;

– additional checkpoints are created at some distance from the main one in order to later determine the travel time of vehicles between them (the length of experimental sections);

– the model is supplemented with information about the actual intensity of movement in order to determine the pattern of change in traffic flow indicators;

– traffic lights are accepted with a certain consistent group of signals that would reflect the mode of control when approaching the regulated intersection;

– meters are installed to record the number of vehicles for which delays are measured relative to the main checkpoint.

After developing the basic model and determining the initial characteristics of a traffic flow, it is possible to simulate its state at any change in input indicators (the intensity and composition of movement).

5. Results of estimating the operational effectiveness of dedicated lanes for public transport

5. 1. Establishing patterns of change in the characteristics of traffic flow at different ways of organizing public transport

The field local observations were carried out on Chornovol Avenue in the city of Lviv during peak periods of the specified working days. In particular, before the introduction (in 2019) and after the introduction (in 2020) of dedicated lanes for public transport throughout its length. This avenue was chosen based on several characteristic features that correspond to the purpose and task of our study: two lanes of traffic in each direction; 6 out of 7 intersections are regulated; it is the main street with a high proportion of transit traffic flows and public transport; the distances between intersections are not the same and do not exceed 200 m, which corresponds to the condition of the basic model created in PTV VISSIM (Germany); the state of traffic flow is characterized by constant saturation. As defined in chapter 4. 1, local measurements of traffic flow indicators were carried out 12 times in the middle of sections of the avenue. To this end, a technique of selective accounting of movement at intervals of 15 minutes was used every 15 minutes. The total duration was 1 hour in the morning and evening peak periods. Based on the study results, we selected the busiest section of the avenue from the regulated intersection with Khimichna Street to the regulated intersection with Pid Dubom Street in the direction «to the center», which has a length of 180 m. The indirect (taking into consideration all 15-minute intervals) traffic flow indicators, determined by the results of our field study, are given in Table 2. They will be subsequently introduced into the basic model.

Table 2

Results of the field study of primary indicators of traffic flow along the section of Chornovol Avenue

Indicator		Left lane[1]		Right lane	
		2019	2020	2019	2020
Average actual traffic intensity, auto/hour		570	810	450	92
Average instantaneous motion speed, km/h		42	34	31	36
The composition of traffic flow, %	passenger	91	92	77	4
	public transport (buses, trolleybuses)	5	3	16	95
	others	4	5	7	1

Note: [1] – the lane bordering the middle of the street

The study results in 2019 and 2020 show that the advantages of introducing dedicated lanes for public transport were an increase in the average instantaneous speed of buses by 16 % (from 31 km/h to 36 km/h) if we compare its value before and after the introduction of such a measure. In addition, the level of uniformity of the traffic flow increased – in the left lane, 92 % of cars, and in the right lane, 95 % of buses. At the same time, the intensity in the left lane increased by about 42 %. In addition, it is worth noting that there is no oversized freight transport in this street due to entry restrictions.

The peculiarity of the selected section is not only its intensity but also the absence of public transport stopping points over the entire length. This makes it possible to analyze a change in the speed of buses in a dedicated lane without taking into consideration the influence of the factor of technological delay necessary for boarding and disembarking of passengers. Since during each of the 15-minute intervals the intensity of bus movement in the selected lane was not the same, it was possible to establish the relationship between this indicator and the speed of movement.

We have derived the dependence of change in the speed of public transport in the selected lane on its intensity. The nature of this change is shown in Fig. 2.

It can be argued that the change (within approximately 47 %) in the intensity of public transport in the dedicated lane from 72 bus/h to 106 bus/h causes a decrease in the speed of traffic in this lane by almost twice. That may cause the rolling stock of public transport to leave for the left lane or lead to an additional delay.

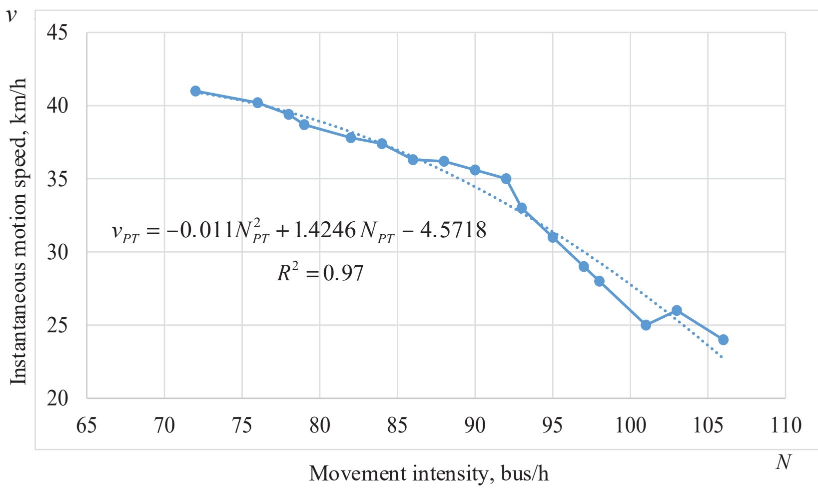

Fig. 2. Change in the instantaneous speed of public transport depending on the intensity of traffic in the selected lane

The introduction of dedicated lanes for public transport often predetermines the congestion of lanes intended for individual transport since new engineering solutions do not provide for the widening of the existing carriageway. Given that most users of individual transport are not ready to use public transport, one should be prepared for the conditions of constant saturation with them in traffic flows not only during peak but also between-peak periods. It is important to note that not all sections of the transport network are loaded equally, especially in cities with radial-ring infrastructure where this phenomenon is observed as it approaches from the periphery to the center. Based on this, researchers face the task of identifying and justifying the feasibility of introducing different ways of prioritizing public transport, including dedicated lanes, in terms of the minimum cost of moving all users of the transport network. In this case, it is important to have information about the state and indicators of individual and public transport over a large area of the city, which can be collected by conducting zonal measurements. The MicroGIS programming environment database, which is used by the Lviv municipal enterprise «Lvivavtodor», makes it possible to determine one of the most important indicators of traffic conditions on the transport network – the speed of connection in its individual sections in real time.

For our zonal studies, two main streets of citywide significance with regulated traffic were chosen in Lviv – Stryys'ka and Kul'parkivs'ka. They have 2 lanes of traffic in each direction. In 2020, public transport mainly operated under a special mode while the intensity of individual transport decreased slightly compared to the previous year. This is due to mobility restrictions caused by the SARS-CoV-2 pandemic. In this regard, data for 2019 were taken in order to analyze the speed of connection along public transport routes.

A report from the MicroGIS program for each vehicle on bus routes that service these mainline streets was obtained by analogy with Table 1. Knowing the actual arrival time of each of them at a stopping point, as well as the distance between these points, one can determine the speed of connection along each section of the route. During this study, it was accepted that the duration of bus stay at a stopping point (excluding terminals) for boarding and disembarking passengers is approximately the same.

Before analyzing the results, the following hypotheses were put forward:

– the constant lag from the established schedule of all buses in certain sections of the transport network may indicate shortcomings in the organization of road traffic or the existence of significant delays in the general traffic flow;

– a comparison of the speed of bus traffic along sections of the street can justify the expediency of introducing certain priority techniques.

Based on the study results, the following speeds of bus connection on the sections of routes were determined (Table 3).

Our analysis of the resulting data shows that when approaching the center there is a typical decrease in traffic speed for main streets, associated with an increase in the intensity and an increase in the density of the street and road network. It should be noted that the distance between the stopping points is almost the same and some displacements of 10–20 m have no significant impact on the growth or fall of speed. At the same time, the situation with the share of buses that cannot comply with schedules is more important. Thus, along the Stryys'ka Street, this phenomenon is manifested at stopping point 6 where 42 % of buses are late relative to the schedule, while along the Kul'parkivs'ka Street – 4, where 52 % of buses are late. It can be argued that along the Stryys'ka Street, between stopping points 1–5 (excluding terminal), there is no need for priority for public transport, as well as along the Kul'parkivs'ka Street, between stopping points 1–3. In the presence of significant delays, it is necessary to decide on the introduction of priority with the arrangement of a dedicated lane for public transport along the entire length of the following sections or in the area of intersections.

Table 3

The results of studying the speed of connection and compliance with traffic schedules on bus routes that run along the Stryys'ka and Kulparkivska Streets

Indicator	Number of stopping point from periphery to center (excluding terminals)								
	1	2	3	4	5	6	7	8	9
Speed of connection along the Stryys'ka Street, km/h	28.6	19.3	22.1	18.2	19.3	14.6	14.3	14.0	13.4
The share of buses that lag behind the schedule along the Stryys'ka Street, %	–	–	4	11	12	42	49	62	69
Speed of connection along the Kulparkivska Street, km/h	26.2	21.8	20.4	15.9	15.7	16.1			
The share of buses that lag behind the schedule along the Kulparkivska Street, %	–	2	7	52	71	82			

One can also apply traffic light control in the direction of approaching buses (trolleybuses) to these intersections. It is necessary to compare the zonal values of the average speed of individual transport and the speed of public traffic. It should be taken into account that the MicroGIS programming environment is designed to monitor only the latter. It would be expedient to conduct a simultaneous mass field study on all sections of the transport network using laboratory cars. This is a challenge for future research. The decision to prioritize the movement of one of the groups of its participants under the conditions of the limited territory is a compromise and should be based on the criteria for ensuring greater mobility with the least time costs.

5. 2. Results of simulating the state of traffic flow

Based on the results of our field study (Table 2) and the simulation technique in PTV VISSIM, we built models of the state of traffic flow in the section of Chornovil Avenue from the regulated intersection with Khimichna Street to the regulated intersection with Pid Dubom Street in the direction «to the center» in two cases:

– simulation under conditions where there are no dedicated lanes for public transport; the increase in the intensity of individual transport is 20 % for each state of the flow relative to the previous one; the intensity of public transport is unchanged;

– simulation under conditions when dedicated lanes for public transport are arranged; the increase in the intensity of individual transport is 20 %, public 5 %, for each state of the flow relative to the previous one.

The simulation results are given in Table 4.

The simulation results in Table 4 are adequate under the appropriate existing time parameters of traffic light regulation. In particular, the duration of the main permitting (green) signal at the traffic light that services this phase is 30 s, and the duration of the regulatory cycle is 66 s. Since the parameters of the phases and the cycle can change, in practice most often used is an indicator that is determined by the ratio of the duration of the permitting signal to the duration of the control cycle and characterizes the proportion of green signal along a given direction in the cycle. The designation «n/a» means that the queue of vehicles along the direction (lane) is outside the area between the intersections, that is, it can block an adjacent intersection if the parameters of the traffic light cycle are unchanged. When determining the length of travel through the intersection and the length of the queue, the programming environment PTV VISSIM applied the averaged value. This is due to the random nature of the process of approaching the intersection, as well as the fact that not all vehicles are delayed before the intersection. Information about the maximum queue length is important when assessing the time parameters of traffic light regulation at high street network density values.

Table 4

Results of simulating the operational efficiency of the regulated intersection in the absence and presence of dedicated lanes for public transport

Simulation of traffic under conditions of increasing traffic intensity without arranged dedicated lanes for public transport					
Measured indicator	Model state number (increase in the intensity of individual transport by 20 %)				
	1 (Base)	2	3	4	5
The intensity of traffic flow that approaches the intersection, auto/h	1,020	1,206	1,429	1,696	2,016
The average duration of travel by one vehicle through the intersection, s	35.4	47.9	56.7	72.3	84.5
The average length of the queue before the intersection during the simulation lasting 1 hour, m	44.3	75.9	104.7	111.8	126.4
Maximum queue length before intersection during simulation time of 1 hour, m	132.7	156.3	165.1	179.8	n/a[1]
Simulation of traffic under conditions of increasing traffic intensity with arranged dedicated lanes for public transport					
Measured indicator	Model state number (increase in the intensity of individual transport by 20 %, public transport by 5 %)				
	1 (Base)	2	3	4	5
Intensity of traffic that approaches the intersection, left lane, auto/h	810	972	1,166	1,399	1,679
The intensity of traffic that approaches the intersection, right lane, auto/h	92	97	102	107	112
The average duration of travel by one vehicle through the intersection, s					
Left lane	82.4	107.3	134.2	160.9	189.7
Right lane	24.3	25.9	28.2	30.4	32.9
The average length of the queue before the intersection during the simulation lasting 1 hour, m					
Left lane	97.2	121.4	142.5	179.8	n/a[1]
Right lane	32.4	37.9	40.2	45.3	49.4
Maximum queue length before intersection during simulation time of 1 hour, m					
Left lane	140.9	170.4	n/a[1]	n/a[1]	n/a[1]
Right lane	78.3	80.4	91.6	101.3	108.5

Note: [1] – the model extends beyond the length of the segment in PTV VISSIM, which is 200 m

6. Discussion of the study results on determining the operational effectiveness of dedicated lanes

Our results of simulating the operational efficiency of regulated intersections in the absence and presence of dedicated lanes for public transport confirm the expediency of their implementation. In particular, a decrease in the total (individual + public transport) intensity of traffic of vehicles was registered, from 1,020 auto/h to 902 auto/h, by 12 % for the base model (Table 4). Similar results regarding the decrease were obtained for the four considered states of the model, taking into consideration the redistribution of traffic flow to individual transport separately in the left lane (by 17–20 %) and public – in the right lane. The share of the latter in the base model is 11 %, for the four other states of the model, this share changed from 10 to 7 %. The redistribution of traffic to individual and public transport reduces the average length of passing the intersection from 35.4 s to 24.3 s (for the base model), the average queue length before the intersection – from 44.3 m to 32.4 m and, accordingly, the maximum queue length from 132.7 m to 78.3 m. For the four models under consideration, there is a reduction in the average length of passing the intersection, from 46 to 61 %, and, accordingly, the average and maximum queue lengths – from 50 to 61 %, and from 40 to 44 %.

The above convincingly indicates the effectiveness of the arrangement of dedicated lanes for public transport as it reduces the duration of passing the crossings and the corresponding lengths of queues. Obviously, this would contribute to complying with traffic schedules, reducing the level of pollution of the city's air pool, transport fatigue of passengers.

In practice, it should be taken into account that the arrangement of a dedicated lane is not yet a guarantee to resolve the issue related to significant improvement in the efficiency of public transport services. Additionally, it is necessary to model the parameters to control traffic lights at regulated intersections and pedestrian crossings. It is also necessary to take into consideration the intensity of public transport along the dedicated lanes, as well as aspects of the technological process that occurs at stopping points.

The proposed set of methods (field measurements, documentary study, and simulation) to determine the indicators of traffic flow is effective. Their results are representative for sections of city main streets with a significant share of transit flows (not less than 70 %), heavy traffic of public transport, and restriction of the distance between adjacent intersections up to 200 m. A certain limitation of the current study is that it does not take into consideration the number of passengers of individual and public transport that use the transport network. Such a drawback can be eliminated in the future if there is information about the number of passengers who used an electronic ticket. Thus, it is possible to compare arrays of data on the number of users of public transport and the speed of their movement along certain sections of the transport network. This information would be more representative when justifying the criteria for arranging dedicated lanes and determining how to prioritize individual and public transport.

The results of our study could be implemented during the development or improvement of automated traffic control systems. It is important to observe the compliance and consistency of implementation. This would minimize the time and cost to identify problem areas of the network and eliminate (or reduce) the impact of negative factors. It should be noted that the outlined scientific and applied approach to determining the effectiveness of the arrangement of dedicated lanes for public transport using modern methods makes it possible to evaluate its efficiency for the intricate street and road network of large cities and make it as accessible as possible for both individual and public transport.

7. Conclusions

1. The proposed set and sequence of transport research methods make it possible to establish the most important indicators that determine the operational effectiveness of those sections of city streets where dedicated lanes for public transport are arranged, at the lowest time and cost. It has been determined that it is possible, in the city main street with a significant share of transit traffic, to increase, after the introduction of dedicated lanes for public transport, its average speed of connection by up to 16 %. The growth of this speed is directly influenced by the intensity of public transport along the dedicated lane.

2. A simulation model of a two-lane section of the street between two intersections with a length of 200 m was built; we modeled different state of flows of individual and public transport (with a steady increase in traffic intensity) using it. It was determined that at this length of the section there are characteristic patterns in the indicators of traffic flow at adjacent intersections. These patterns make it possible to synchronize the control parameters of the traffic lights. Based on the simulation results, it was established that for such areas the maximum possible traffic intensity along the dedicated transport lane is 972 units per hour. It was determined that before and after the introduction of the dedicated lanes, the duration of travel over such a section by one bus decreases from 72.3 s to 25.9 s.

References

1. Ben-Dor, G., Ben-Elia, E., Benenson, I. (2018). Assessing the Impacts of Dedicated Bus Lanes on Urban Traffic Congestion and Modal Split with an Agent-Based Model. Procedia Computer Science, 130, 824–829. doi: https://doi.org/10.1016/j.procs.2018.04.071
2. Vrubel', Yu. A. (2003). Poteri v dorozhnom dvizhenii. Minsk: BNTU, 380.
3. Bakulich, O. O., Dziuba, O. P., Yeresov, V. I.; Polishchuk, V. P. (Ed.) (2011). Orhanizatsiya ta rehuliuvannia dorozhnoho rukhu. Kyiv: Znannia Ukrainy, 467.
4. Fadyushin, A., Zakharov, D. (2020). Influence of the Parameters of the Bus Lane and the Bus Stop on the Delays of Private and Public Transport. Sustainability, 12 (22). doi: http://doi.org/10.3390/su12229593
5. Fadyushin, A., Zakharov, D., Karmanov, D. (2018). Estimation of the change in the parameters of traffic in the organization of the bus lane. Transportation Research Procedia, 36, 166–172. doi: https://doi.org/10.1016/j.trpro.2018.12.059

6. Chen, Y., Chen, G., Wu, K. (2016). Evaluation of Performance of Bus Lanes on Urban Expressway Using Paramics Micro-simulation Model. Procedia Engineering, 137, 523–530. doi: https://doi.org/10.1016/j.proeng.2016.01.288
7. Breski, D., Cvitanic, D., Dumanic, D. (2018). Impact of Exclusive Bus Lane on Urban Arterial Performance Measures. Proceedings of the 5th International Conference on Road and Rail Infrastructures – CETRA 2018. Zagreb: Tiskara Zelina, 1579–1585. doi: https://doi.org/10.5592/CO/cetra.2018.746
8. Shaaban, K., Ghanim, M. (2018). Evaluation of Transit Signal Priority Implementation for Bus Transit along a Major Arterial Using Microsimulation. Procedia Computer Science, 130, 82–89. doi: https://doi.org/10.1016/j.procs.2018.04.015
9. Furth, P. G., Muller, T. H. J. (2000). Conditional Bus Priority at Signalized Intersections: Better Service with Less Traffic Disruption. Transportation Research Record, 1731 (1), 23–30. doi: https://doi.org/10.3141/1731-04
10. Anderson, P., Daganzo, C. F. (2019). Effect of Transit Signal Priority on Bus Service Reliability. Transportation Research Procedia, 38, 2–19. doi: https://doi.org/10.1016/j.trpro.2019.05.002
11. Dumbliauskas, V., Grigonis, V., Vitkiene, J. (2017). Estimating the Effects of Public Transport Priority Measures at Signal Controlled Intersections. The Baltic Journal of Road and Bridge Engineering, 12 (3), 187–192. doi: https://doi.org/10.3846/bjrbe.2017.23
12. Wang, D., Liu, C. S. (2018). Research on Priority Control Method of Conventional Public Traffic Signals. IOP Conference Series: Earth and Environmental Science, 189, 062053. doi: https://doi.org/10.1088/1755-1315/189/6/062053
13. Hua, X., Wang, W., Wang, Y., Pu, Z. (2017). Optimizing phase compression for transit signal priority at isolated intersections. Transport, 32 (4), 386–397. doi: https://doi.org/10.3846/16484142.2017.1345787
14. Guler, S. I., Gayah, V. V., Menendez, M. (2015). Providing Bus Priority at Signalized Intersections with Single-lane Approaches. Transportation Research Procedia, 9, 225–245. doi: https://doi.org/10.1016/j.trpro.2015.07.013
15. Bauer, M. (2014). Bus running time onto sections with designated bus lanes modelling. Logistyka, 4, 2677–2686. Available at: https://www.researchgate.net/publication/303647305_Bus_running_time_onto_sections_with_designated_bus_lanes_modelling
16. Gitelman, V., Korchatov, A., Elias, W. (2020). An Examination of the Safety Impacts of Bus Priority Routes in Major Israeli Cities. Sustainability, 12 (20), 8617. doi: https://doi.org/10.3390/su12208617