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ASSESSMENT OF THE IMPACT OF TRAFFIC CONDITIONS ON THE AVAILABILITY OF TRANSPORT SERVICES OF THE CITY BUS ROUTE

The object of research is the influence of the conditions for the implementation of technological trip operations in the implementation of the priority movement of urban passenger transport on the bus route on the level of accessibility of the transport service. On the basis of the developed contour of information communication, a typical procedure for establishing the parameter for assessing the availability of a transport service, depending on the time indicators of traffic on the route, is singled out. As a controlled parameter that determines the conditions for increasing the availability of a transport service, the trip time and the range of deviations in the arrival of buses to the stopping point are singled out. Implemented on the basis of simulation modeling, the procedure for establishing the correspondence between the time parameters of the departure of buses from the stopping point and the formation of demand made it possible to establish patterns of changes in the level of accessibility of the transport service depending on the traffic conditions on the route.

In the course of field observations along route No. 115e «Gagarin avenue metro station – Nesterov street» (Kharkiv, Ukraine) it was found that the introduction of free traffic conditions that meet the conditions of the priority of urban passenger transport can reduce the duration of the trip by 5 min and reduce the range of deviation of the arrival of buses to the stopping point by 4 min. On the basis of experimental studies, it was found that by reducing the duration of the trip from 32 min up to 27 min it is possible to increase the value of the transport service accessibility indicator by 20.5 %. When organizing traffic according to a schedule, it is possible to increase the indicator of the availability of transport services up to 0.679 (by 6.8 %). The introduction of priority traffic on route No. 115e allows reducing the trip time to 22–27 min, which will positively affect the indicator of the availability of transport services (increase to 0.803 in traffic without a schedule and up to 0.880 in compliance with the traffic schedule). Reducing the range of bus arrival deviations in the range from –1 min up to +2 min allows increasing the level of accessibility of transport services under normal conditions from 6.8 % to 13.3 %, and with the introduction of priority traffic – from 15.4 % to 18.3 %.

Keywords: *urban passenger transport, availability of transport services, bus arrival, service quality.*

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1. Introduction

Improving the quality of transport services to the population (QTSP) in cities is an urgent scientific and practical task. The development of measures to increase the QTSP is considered as the main task of improving urban passenger transport (PTU) [1]. Among the main directions for increasing the RATON, approaches based on:

– improvement of the route network configuration [2];
– choice of the type and capacity of the rolling stock [3];
– establishment of rational traffic modes on routes [4];
– reducing the time of inter-route transfers [5];
– increasing the speed mode of movement [6];
– improving the level of information support for passengers [7].

At the stage of designing the UPT management system, it is imperative to evaluate the effectiveness of the selected measure in relation to the indicators of QTSP. For the objectivity of reflecting the QTSP state, it is advisable to use a hierarchical structure of evaluation indicators [8]. In such a structure, a fundamental indicator is distinguished, which at other levels can be detailed through derived parameters. It is proposed to use the availability of transport services as a base indicator for assessing QTSP. The availability of a transport service is its ability to perform the functions of timely satisfaction of the movement of the population at certain limit values of the QTSP. The level of accessibility is determined by the ratio of the demand for transport services presented by the population in the period and the volume of the provided transport offer.

As a reproducing indicator, demand is the volume of passengers arriving at the stopping point of the route, and as a supply, the carrying capacity of buses, which are represented by the distribution of trips over a period of time. If demand exceeds capacity or there are significant periods of time when passenger waiting time exceeds the allowable limit, a situation arises in which a proportion of passengers will not be able to use the route in time. Such a state, by its nature, meets the conditions of a critical service incident and is unacceptable from the point of view of QTSP. Prevention of the occurrence of a critical incident situation implies an increase in the carrying capacity of the UPT, which can be ensured by an increase in the number of rolling stock, its capacity or a reduction in the duration of the trip. Increasing the rolling stock fleet or replacing it with a larger capacity requires capital investments and leads to a decrease in the economic efficiency of the UPT [9].

Reducing the trip time allows increasing the productivity of the rolling stock and, as a result, increasing the volume of the transport offers with the same amount of resources involved. Among the main measures to reduce trip time can be applied:

– coordination of bus idle processes at stopping points [10];
– introduction of express and combined traffic modes [11];
– increasing the speed of buses on routes [12].

The main disadvantage of methods based on the coordination of bus idle processes at stopping points [13] is their low efficiency in relation to the specific part of the reduction in trip time. According to the results of a survey of the duration of the trip on the bus route No. 115e «Gagarin avenue metro station – Nesterov street» (Kharkiv, Ukraine) it was found that in the morning the duration of idle time of buses at stopping points is from 17 % to 26 % of the duration of the trip. At the same time, there are no unproductive components in the downtime structure at stopping points, which, in fact, makes it impossible to actually reduce the trip time. The introduction of an express mode of movement is possible only if there is no passenger exchange at intermediate stopping points [14]. For urban transportation, such conditions are in most cases impossible.

The increase in speed on the route is achieved primarily through the introduction of priority route traffic on sections of the road network. The introduction of the priority of the UPT allows creating conditions for free movement, which is a prerequisite for the complete elimination of time delays on the race route. However, such an event can be implemented only on certain sections of the streets, where there are enough traffic lanes for this. At the same time, reducing the number of lanes for non-route vehicles will lead to more difficult conditions for their movement. Therefore, the decision to introduce the priority movement of the UPT requires a preliminary analysis from the standpoint of assessing its effectiveness in relation to the change in the level of UPT availability, which will make it possible to conclude in the future on the advisability of introducing such a management decision. So, *the object of the study* is the influence of the conditions for the implementation of technological trip operations on the bus route on the level of accessibility of the transport service during the introduction of the priority movement of the UPT. *The aim of research* is to establish a characteristic relationship between the temporal parameters of bus traffic when introducing the UPT priority traffic to the level of accessibility of the transport service.

2. Research methodology

The methodological basis for determining the impact of the UPT priority movement on the availability of transport services is analytical models that establish a structural and logical relationship between the demand presented, the duration of technological trip operations and the volume of the provided transport offer. The level of accessibility of transport services is estimated by the proportion of timely departures of passengers in the period:

$$A_p^r(T_p)=\sum_{i=1}^{n_{sp}}\frac{Q_i^o(T_p)}{Q_i^p(T_p)}, \tag{1}$$

where $Q_i^o(T_p)$ – volume of passengers who departed on time from the stopping point i in the period T_p, passengers; $Q_i^p(T_p)$ – volume of passengers arriving at the stopping point i during the period T_p, passengers; n_{sp} – the number of stopping points on the route; T_p – duration of the period, hour.

The condition that determines belonging to the timely departure of a passenger from the stopping point sp is compliance with the maximum allowable waiting time:

$$t_{sp_i}^w \le t_{sp}^a, (i=\overline{1,Q_i^p}), \tag{2}$$

where $t_{sp_i}^w$ – waiting time for the departure of the i-th passenger, min; t_{sp}^a – maximum waiting time for passenger departure for stopping point sp, min.

The procedure for determining the volume of timely departing passengers provides for the establishment in the period T_p of the moments of arrival at the bus stop for each trip ($t_{sp_i}^b$) and each passenger ($t_{sp_i}^p$). Based on the determination of the duration of the current waiting time, the possibility of a timely trip by the passenger is established. The volume of passengers who departed from the stopping point on time is determined by the following conditions:

$$Q_i^o(T_p)=\sum_{j=1}^{Q_{spi}^p} q_{ij}^p,$$
$$\begin{cases} q_{ij}^p=1, \text{ if } t_{sp_i}^w \le t_{sp}^w \text{ and } \gamma_{sp_{ju}}^b \le 1, \ (u=\overline{1,N^b}), \\ q_{ij}^p=0, \text{ if } t_{sp_i}^w > t_{sp}^w \text{ and } \gamma_{sp_{ju}}^b > 1, \ (u=\overline{1,N^b}), \end{cases} \tag{3}$$

where q_{ij}^p – binary value of the passenger belonging to the group of those who departed on time from the stopping point (takes the value 1 or 0); Q_{spi}^p – total number of passengers departing in the period T_p, passengers; $\gamma_{sp\gamma_{ju}}^b$ – static capacity utilization factor of the bus j; N^b – the number of trips arriving at the stopping point.

Establishing the value of the level of accessibility of a transport service involves the calculation of the time parameters for the formation of a transport offer within a separate stopping point. The moment of arrival of the bus at the stopping point sp_i is determined by the interval of movement ($I_{sp_i}^b$) and the deviation of the arrival of the trip at the stopping point ($\Delta I_{sp_i}^{b_j}$):

$$t_{sp_i}^{b_j}=I_{sp_i}^b+\Delta I_{sp_i}^{b_j}, \tag{4}$$

where $I_{sp_i}^b$ – interval of bus traffic, min; $\Delta I_{sp_i}^{b_j}$ – deviation of the bus arrival to the stopping point, min.

The interval of movement depends on the time of the trip and the number of buses on the route:

$$I_{sp_i}^b = \frac{t_p^f + t_p^r}{N_b} = \frac{\sum_{i=1}^{p_l} t_i^l + \sum_{j=1}^{p_{ts}} t_j^{ts} + t^{es}}{N_b}, \quad (5)$$

where t_p^f – trip time in the forward direction, min; t_p^r – trip time in the opposite direction, min; t_i^l – travel time on the i-th stage of the route, min; t_j^{ts} – idle time at the j-th intermediate stop, min; t^{es} – idle time at the final stop, min; p_l – the number of route races, units; p_{ts} – the number of intermediate stopping points on the route, units; N_b – the number of buses on the route, units.

The procedure for establishing the parameters of the availability of a transport service is described by the contour of information communication (Fig. 1).

The basis for determining the level of transport demand is the establishment of information about the moments of coming of passengers ($t_{sp_i}^p$) to each stopping point $sp_i, (i=\overline{1,n_{sp}})$. This information contains a data array $(M_{sp}=\{q_{spi}^p\}, (i=\overline{1,T_p}))$ in which the ordinal elements are represented by time points $(t_i, (i=\overline{1,T_p}))$ and the number of passengers $(q_{spi}^p(t_i))$ arriving at the stopping point. The offer is represented by the number of buses (M^b), their capacity (q_n^b) and depends on the duration of technological operations $(t_i^l, t_j^{ts}, t^{es}, (i=\overline{1,p_l}), (j=\overline{1,p_{ts}}))$, which together determine the trip time (t_p). The implementation of technological operations can be carried out under the conditions of free movement of buses on the network (implementation of the UPT priority) or under normal conditions. Depending on the traffic conditions, the total duration of the trip t_p changes, the interval of movement on the route ($I_{sp_i}^b$) and the range of deviation of the arrival of buses ($\Delta I_{sp_i}^{b_j}$) change accordingly. Depending on the actual value $t_{sp_i}^b$ and $t_{sp_i}^p$, the degree of belonging of the passenger q_{ij}^p to the group of those who departed on time from the stopping point is determined. If condition (2) follows, then the passenger will go on this trip. At the time when it is not fulfilled, the passenger can use another alternative route, which is essentially a sign of a critical service incident and indicates a low availability of the transport service.

The central control element is to establish the influence of the conditions for the implementation of motor operations on the moments of the bus arrival ($t_{sp_i}^b$). Under normal conditions of movement along the route, an increase in trip time is observed and the unevenness of arrival increases to a large extent.

As a result, the proportion of passengers arriving at a stopping point may be waiting for a departure longer than their set waiting time limit t_{sp}^a. This, in turn, leads to a decrease $Q_i^o(T_p)$ and, as a result, to a decrease $A_p^r(T_p)$. The reduction $\Delta I_{sp_i}^{b_j}$ is achieved by creating conditions under which bus drivers can ensure the reliability of the schedule for the route. With the introduction of priority movement, the regularity of movement is greatly increased by reducing $I_{sp_i}^b$ and the range $\Delta I_{sp_i}^{b_j}$. At the same time, a reduction in the waiting time for passengers is achieved, which positively affects the increase in $Q_i^o(T_p)$ and $A_p^r(T_p)$. Establishing a characteristic relationship between the conditions of motor operations and parameters $A_p^r(T_p)$ is possible on the basis of field observations of the flow of passengers and modeling the processes of arrival of buses at a stopping point. The incoming flow of passengers to the stopping point is determined by field observations. The card records the moment of time and the number of passengers approaching the stopping point. In this way, fixed values $t_{sp_i}^p$ are determined for the entire period T_p. The value $t_{sp_i}^b$ is determined on the basis of simulation by setting values t_i^l, t_j^{ts}, t^{es} for different conditions of the movement along the route.

As part of the simulation experiment, the stopping point «metro station Gagarin avenue» (49.98046, 36.24407), from which bus route No. 115e «Gagarin avenue metro station – Nesterov street» (Kharkiv, Ukraine). To study the formation of passenger traffic on the route, the time period from 16 to 18 hours was chosen. This period is characterized by the concentration of the main volume of passenger departures at the selected stopping point and the presence of complication of traffic along the sections of the route along Gagarin Avenue.

On the basis of field observations, the actual time moments of the approach of passengers to the stopping point were established. The collection of primary information on the duration of motor operations for two types of movement (normal and free with the provision of conditions for the UPT priority movement) was implemented using field observations. The total number of observations was 112 trips for normal conditions and 52 trips for free movement. Free traffic conditions were established for the morning period from 6 to 7 o'clock, when there was no heavy traffic on the street network. Later, on their basis, the average values of the parameters and the laws of distribution of random variables were established.

The characteristics of the time parameters of movement along the route are given in Table 1.

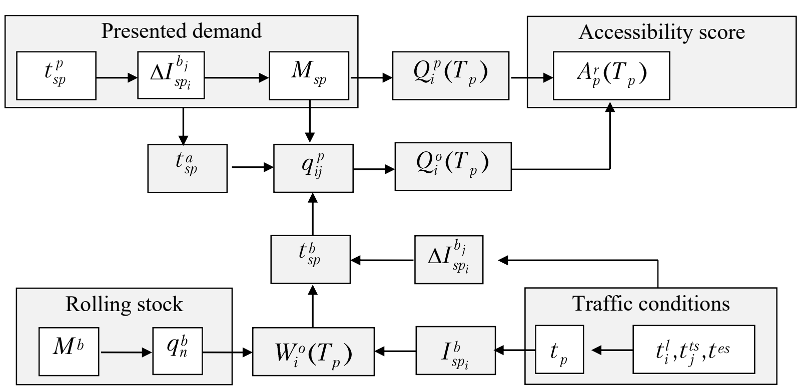

Fig. 1. The contour of information communication for the formation of the availability of transport services

Table 1

Characteristics of motor operations on route No. 115e

Index	Normal traffic (without UPT priority)	Free traffic (with UPT priority)
Direct direction of movement «Gagarin avenue metro station – Nesterov street»		
Trip duration, min	28–32	22–27
Travel time, min	22–26	16–21
Downtime at intermediate stops, min	6–9	6–8
Idle time at the final stop, min	2	2
Deviation of arrival, min	from –2 min to +5 min	from –1 min to +2 min
Law of interval distribution	Gamma distribution	Gamma distribution
Direction of movement «Nesterov street – Gagarin avenue metro station»		
Trip duration, min	27–30	22–25
Travel time, min	21–24	16–19
Idle time at intermediate stops, min	6–8	6–8
Idle time at the final stop, min	2	2
Deviation of arrival, min	from –2 min to +4 min	from –1 min to +1 min
Law of interval distribution	Gamma distribution	Gamma distribution

Simulation modeling was implemented using the ModellingSP program developed at the Department of Transport Technologies of the Kharkiv National Automobile and Highway University (Ukraine). During the simulation for two variants of traffic conditions, 12 series of experiments were carried out. Each episode is a separate period of time from 16:00 to 18:00. In total, the situation of arrival at the stopping point of 134 bus routes was simulated.

3. Research results and discussion

Simulation modeling is aimed at obtaining a set of indicator values that allow establishing a characteristic relationship between the traffic conditions along the route and the level of availability of the transport service. The influence of the conditions for the implementation of motor operations on the parameters of the availability of a transport service is manifested due to a change in the duration of the trip and the deviation of the arrival of buses at the stopping point. Based on the results of field observations, it was found that under normal traffic conditions, the time of the trip along the route in the study period varies from 27 min to 32 min, and for conditions with priority UPT – from 22 min to 27 min. It is advisable to consider the deviation of the arrival interval in two ways: in compliance with the traffic schedule and in complicated conditions without compliance with the schedule. Based on this, the base values that reproduce the conditions for the convenience of the movement of buses on the route are the trip time t_p and the deviation of the arrival interval $\Delta I_{sp_i}^{b_j}$. For each option, two possible ranges of change in the arrival interval were considered: on schedule $(-1\text{ min} \le \Delta I_{sp_i}^{b_j} \le +2\text{ min})$ and in complicated conditions without schedule $(-2\text{ min} \le \Delta I_{sp_i}^{b_j} \le +5\text{ min})$. Fig. 2 shows the changes $A_p^r(T_p)$ from t_p and $\Delta I_{sp_i}^{b_j}$ for normal driving conditions, and in Fig. 3 – for conditions with dedicated lanes for UPT.

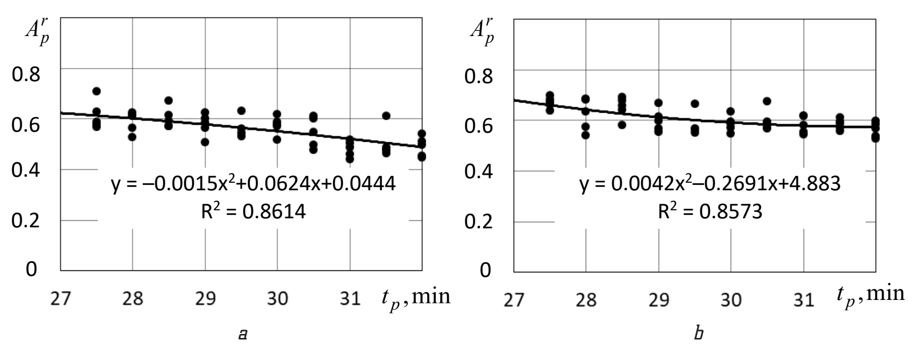

Fig. 2. Changing the availability of transport services for the stopping point «Gagarin avenue metro station» without the UPT priority: *a* – arrival deviation from –2 min up to +5 min; *b* – arrival deviation from –1 min up to +2 min

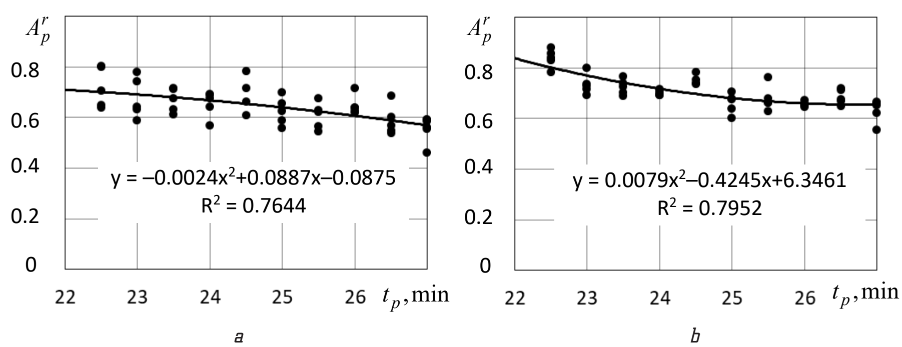

Fig. 3. Changing the availability of transport services for the stopping point «Gagarin avenue metro station» with the UPT priority: *a* – arrival deviation from –2 min up to +5 min; *b* – arrival deviation from –1 min up to +2 min

Analyzing the above graphs, it is possible to establish a number of features of changes in the availability of transport services, which are determined by the conditions for the implementation of motor operations on the route with various forms of traffic organization. The dispersion of the obtained values is explained by the fluctuation of the deviation values of the arrival interval used as a random variable. The obtained dependences are described by polynomials of the second stage with a sufficient level of approximation reliability (the value of the coefficient of determination R^2 is in the range from 0.7644 to 0.8614). In the conditions of traffic without the priority of the UPT and without following the schedule, it is possible to change the value of the transport service availability indicator $A_p^r(T_p)$ in the range from 0.441 to 0.672. Reduction of trip time from 32 min up to 27 min allows increasing the value of the indicator $A_p^r(T_p)$ for the established trend by 20.5 %. In the case of organization of traffic without priority, but in compliance with the schedule, it is possible to obtain the value of the transport service availability indicator $A_p^r(T_p)$ in the range from 0.528 to 0.7. The reduction in trip time within the range under consideration provides a 15.7 % increase. The organization of traffic in compliance with the schedule provides an increase $A_p^r(T_p)$ from 6.8 % (at $t_p = 27$ min) to 13.3 % (at $t_p = 32$ min). The increase in the rate of improvement $A_p^r(T_p)$ with an increase in trip time indicates the effectiveness of the management of the UPT in the direction of increasing the regularity of the message on the route. When creating free conditions for the movement of buses along the route (with the UPT priority), it is possible to change the value of the indicator $A_p^r(T_p)$ in the range from 0.547 to 0.803 without observing the traffic schedule and in the range from 0.603 to 0.880 with compliance with the traffic schedule. While ensuring the minimum possible trip duration ($t_p = 22$ min), it is expected to increase the transport service availability indicator for the established trend by 20.6 % for conditions without compliance with the schedule and by 22.5 % for conditions with compliance with the schedule. Comparing the options for movement along the route in the conditions of the UPT priority, it was found that when introducing movement in compliance with the traffic schedule, it is possible to increase the transport service availability indicator for the established trend from 15.4 % (at $t_p = 27$ min) to 18.3 % (at $t_p = 22$ min). At the same time, there is a trend in which the increase in the indicator $A_p^r(T_p)$ is more influential with the minimum duration of the trip.

The established patterns reproduce the general trend of the influence of traffic conditions on the availability of transport services. The value of the change in the share of departed passengers in a timely manner may differ depending on the nature of the formation of demand at stopping points and the configuration of the route. For long distance routes, the improvement in accessibility with the introduction of priority traffic will be more pronounced, which is explained by the possibility of a significant reduction in travel time and traffic interval. In the conditions of an ordinary flow, the formation of demand at stopping points, improving the regularity of communication through the organization of priority traffic will have a greater positive impact. To obtain objective data on changes in the level of accessibility of transport services, it is necessary to implement a procedure for simulating technological operations, which involves the creation of a complex model that uses actual data on the formation of passenger departures in time and the duration of motor operations. The patterns obtained indicate the effectiveness of using the methods of organizing the UPT priority movement as an effective mechanism for QTSP improvement. Based on the analysis of the obtained characteristic patterns, it is possible to substantiate the need to develop and implement a comprehensive program for coordinating the movement of buses on routes.

4. Conclusions

In the course of the study, it has been found that increasing the level of accessibility of transport services is possible by creating conditions conducive to reducing the duration of motor operations and reducing the deviation of the arrival of buses at the stopping point. In practice, such conditions are provided by organizing the UPT priority movement along sections of the road network. The assessment of the influence of the conditions for the reduction of motor operations on the availability of transport services is implemented on the basis of modeling the processes of supply and demand formation within the local bus route stopping point. The methodological basis of simulation modeling is analytical models that establish a structural and logical relationship between the demand presented, the duration of technological trip operations and the volume of the provided transport offer.

An information communication loop has been developed, which made it possible to single out a typical procedure for determining the parameters of the availability of a transport service, depending on the time indicators of traffic on the routes. The basis for determining the level of availability of a transport service is the establishment of information about the moments of approach of passengers to the stopping point, the moment of arrival of vehicles and the maximum allowable waiting time for passengers. As a controlled parameter that determines the conditions for increasing the availability of a transport service, the trip time and the range of deviations in the arrival of buses to the stopping point are singled out.

Based on the simulation for the stopping point «Gagarin avenue metro station» (49.98046, 36.24407), characteristic patterns of changes in the level of accessibility of the transport service from the time parameters of the movement of buses of route No. 115e «Gagarin avenue metro station – Nesterov street» (Kharkiv, Ukraine). For conditions without strict adherence to the traffic schedule, the value of the indicator of the availability of transport services is in the range from 0.441 to 0.672, which indicates a low level of quality of transport services for passengers on the route. By reducing the trip duration from 32 min up to 27 min it is possible to increase the value of the transport service availability indicator for the established trend by 20.5 %. In the case of organizing traffic in compliance with the schedule, it is possible to increase the indicator of the availability of transport services to 0.679 (by 6.8 % compared to the baseline). With the introduction of the UPT priority movement, it is possible to reduce the trip time to 22–27 min. This will have a positive impact on the indicator of the availability of transport services (increase to 0.803 in conditions without compliance with the schedule and up to 0.880 with compliance with the schedule).

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Based on the results of the analysis of the data obtained, it has been found that an important role in increasing the transport service availability level service is played by ensuring a high level of regular arrival of buses at the stopping point. Reducing the range of bus arrival deviations in the range from –1 min up to +2 min allows increasing the level of accessibility of transport services under normal conditions from 6.8 % to 13.3 %, and with the introduction of priority traffic – from 15.4 % to 18.3 %. This testifies to the expediency of creating a control system for the UPT, aimed at ensuring a high level of traffic regularity on the routes.

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