Ensuring priority of public urban passenger transport on urban road network

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Abstract. Recently, in large and medium-sized cities, the increase in a load of highways is aggravated by the growth of motorization and the lack of development of the road network. An increase in the traffic intensity of vehicles to a critical level leads to an excess of the throughput of highways. The consequence is an increase in the level of road traffic delay. One of the most vulnerable groups is public urban mass passenger transport. This article discusses the methodology for determining the need to allocate a separate lane for the movement of public urban passenger transport on a given section of the road network. The purpose of this work is to identify patterns between the parameters of traffic flows and the parameters of the transportation program for public urban passenger transport, based on which criteria will be formulated for the need to allocate a separate lane for the movement of urban land transport on each separate section of the route network. For quality improvement of passenger transportation, a mathematical model has been developed, which is based on such indicators as the level of traffic delay and the share of the passenger flow in the total flow of traffic participants. Necessary conditions have been formulated, the strict implementation of which determines the need to ensure the priority of urban mass public transport on the considered section of the city's road network. The resulting dependencies allow determining the need to ensure the priority of urban transport. The proposed model makes it possible to determine the rationality of the allocation of individual lanes, traffic for public transport following the level of traffic in the city's road network. This study can become the basis for an algorithm for the operation of interactive signs that regulate traffic on a given stretch of the city's road network.

1. Introduction
For unload the city's road network, it is necessary to reduce the level of car traffic. One of the effective measures aimed at solving this problem is the task of increasing the attractiveness of urban mass passenger transport. That is, this task is the task of ensuring a sufficient level of passenger service, including the one consisting of a high speed of communication, which can be increased by giving priority to the movement of buses.

One of the promising directions for prioritizing public transport is the arrangement of separate lanes or streets for the movement of only the rolling stock of urban transport. In Krasnoyarsk, the first dedicated lanes for the movement of urban public transport appeared at the end of the nineties of the last century. Corresponding markings and road signs appeared on the central streets of the city. However, the above activities did not bring the desired effect. The reason for this is the massive violation of traffic rules by drivers of vehicles belonging to individual owners and taxi companies.
Most of the carriageway allocated for the movement of public urban passenger transport was operated in a parking space mode. Consequently, bus drivers were forced to move in other lanes. Also, the problem was aggravated by the lack of control by the city administration over the regularity of urban passenger transport. "In pursuit of the ruble," drivers of urban passenger transport were forced to violate the speed limit established by traffic rules, endangering passengers.

With the advent of video recording complexes for traffic violations and complexes for monitoring the regularity of the rolling stock of public urban passenger transport, the situation has changed radically. The lanes allocated for the movement of urban transport began to be used for their intended purpose. Due to the lack of criteria according to which it is necessary to allocate separate lanes for the movement of urban transport rolling stock, they began to appear in the overwhelming majority on the main streets of the city. A large number of city highways appeared, used for the operation of only one route for the movement of urban public transport, with the organization of dedicated lanes on them. The need for such organizational measures is questionable; therefore, on some streets of the city of Krasnoyarsk, the allocated lanes for the movement of urban passenger transport are periodically canceled. Therefore, we need criteria that substantiate the need to allocate a separate lane for urban passenger transport on a given stretch of the city's route network.

Thus, the purpose of this work is to identify patterns between the parameters of traffic flows and the parameters of the transportation program for public urban passenger transport, based on which criteria will be formulated for the need to allocate a separate lane for the movement of urban land transport on each separately taken section of the route network.

2. Short review

There are active and passive methods of priority admission of urban mass passenger transport. The active methods include the methods of passing through the direct impact on the traffic light object [1].

This paper substantiates the feasibility of allocating lanes for the movement of urban mass passenger transport in general use.

The first step in domestic practice on the way of justifying the expediency of allocating lanes was the "Instruction on the organization of priority movement of public transport vehicles" approved by the USSR Ministry of Internal Affairs and the RSFSR Ministry of Automobile Transport in 19831. According to this document, it is advisable to carry out priority traffic in the form of dedicated lanes if the following conditions are met:
- traffic intensity of public transport is not less than 40 units / hour;
- the traffic intensity of other vehicles (per one lane) is not less than 400 reduced units / hour;
- there are at least three lanes in one direction;
- the capacity of the road as a result of the allocation of a lane for public transport will be sufficient for the passage of other vehicles; traffic safety is not reduced, and an acceptable amount of delays is provided.

To date, the practical application of the instruction is impractical, since the given normative values of the motion parameters are outdated.

In the work of O.V. Popov, the main criterion for the expediency of allocating priority movement of urban public transport along the allocated lanes is the minimum total time spent on the movement of participants in the transport process. The author proposes to compare the capacity of a section of the road network with the traffic intensity of vehicles, excluding public transport [2].

Yu.D. Shelkov considers the following indicators to be the main factors for deciding on the possibility of allocating lanes intended for the movement of urban mass passenger transport2:

1 Instructions on the organization of priority traffic of public transport vehicles. Approved by the USSR Ministry of Internal Affairs on 06/30/83, by the RSFSR Ministry of Transport on 06/28/83. Moscow: Transport, 1984, 32p.

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- traffic intensity of public transport;
- traffic intensity of non-priority modes of transport;
- the number of lanes in the direction in question.

As the primary criterion for making a decision on the possibility of organizing dedicated bands in the studies of S.I. Smirnov advocates a reduction in the value of the total cost of delays of various types of vehicles. A mathematical description of the total cost of delays is given in the works of F.V. Akopov, N.O. Bludyan, R.S. Airieva, P.I. Kheifits and M.R. Yakimov [3–8].

Zyryanov V.V., Mironchuk A.A. in their study [9-11], they consider the development of methods for organizing priority traffic on the road network, namely, the concept of priority dedicated discontinuous lanes (PDDL). J. Vigas first described this concept in 1996. The PDDL system algorithm is carried out in the following stages:
- in the absence of buses on the road network section, all lanes are open for individual transport;
- when the bus approaches the PDDL at the calculated distance, the PDDL system is activated;
- activation is carried out by turning on controlled road signs;
- by the time the bus approaches, the priority lane is freed from individual transport; vehicles entering the PDDL section are prohibited from entering and changing lanes to the priority lane;
- the bus passes through the site in priority conditions;
- after the bus leaves the active section, the PDDL lane again becomes available for individual transport.

Assessment of the efficiency of allocated lanes for urban public transport is considered in the work of A.A. Fadyushina, D.S. Karmanov [12]. The assessment is carried out by determining the optimal parameters of the lane for public vehicles without widening the carriageway, and it is taken into account that for private vehicles, the traffic conditions should not worsen.

I.I.Shlippe, L.Yu. Chernobaeva, A.V. Akhterov consider in their work an approach to analyzing the effectiveness of creating dedicated lanes for city bus routes [13]. The assessment is made based on the economic assessment of the free time of the consumer of the transport service on the city public transport. The disadvantages of allocating a lane for public transport and damage to individual traffic are also considered.

The substantiation of the possibility of allocating lanes for the movement of urban passenger transport based on an integral indicator that takes into account the level of traffic on the road network and the level of passenger flow of the section under consideration was proposed in the studies of A.M. Belova [14-16].

In the works of scientists from the USA, Great Britain, South Korea and other countries, the following indicators are highlighted as the main factors for deciding on the possibility of allocating lanes intended for the movement of urban mass passenger transport [17]:
- the minimum value of the traffic intensity of priority types of transport;
- passenger traffic on the considered section of the road network.

In foreign practice, there are such network criteria as buffer index and buffer time or time buffer [18-22]. These parameters have become widely used for assessing the quality of traffic management in many countries.

Travel time index $TTI$ is the ratio of the time taken by a vehicle to pass a section of the road network during peak periods to travel time under free-flow conditions:

$$TTI = \frac{T_{PP}}{T_{FF}},$$

where $T_{PP}$ is the time taken by the vehicle to pass the section in rush hour conditions, min;

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2 Organization of traffic in cities: Methodological manual; Yu.D. Shelkova (ed.) / Research Center of the State Automobile Inspection of the Ministry of Internal Affairs of Russia. Moscow, 1995, 143 p.
TFF is the time taken by the vehicle to pass the section in free traffic conditions, min.
The time index TTI is mathematically quite simple to determine and allows assessing the impact of high loads on traffic conditions on urban and suburban roads.
The scope of the temporary index:
- assessment of the impact of high load on traffic conditions on segments of city streets and roads;
- assessment of the influence of the transport network load on time spent on moving along this network;
- comparative analysis of road conditions and the traffic quality management (TQM) in different cities or different areas of the city;
- assessment of the impact of high load on traffic conditions on country roads (access to cities, bypassing cities, main roads).
Table 1 contains data that allows evaluating the quality of traffic management on highways.

**Table 1. Evaluating traffic conditions on city street and road segments**

| Service level | Time index value TTI | Driving conditions |
|---------------|----------------------|--------------------|
| A             | ≪1,2                 | There is no deterioration in driving conditions during peak periods, excellent driving conditions. |
| B             | 1,21 – 1,3           | During peak periods, there is a slight deterioration in traffic conditions. |
| C             | 1,31 – 1,5           | During peak periods, there is a deterioration in traffic conditions. |
| D             | 1,51 – 2             | During peak periods, there is a significant deterioration in traffic conditions, satisfactory traffic conditions. |
| E             | ≫2,1                 | During peak periods, the segment does not function reliably. There may be congestion, poor traffic conditions. |

The buffer time is estimated as the additional time $T_b$ required to achieve the goal of movement with given reliability, for example, with a reliability of 90% or 95%. Accordingly, $T_b$ is defined as the difference

$$T_b = T_{90\%}(95\%) - \bar{T},$$

where $T_{90\%}(95\%)$ is the duration of movement with 90% or 95% availability;
$\bar{T}$ is the average travel time.
The indicator under consideration characterizes the reliability of the functioning of the urban road network or road network. In this case, the buffer time $T_b$ can be used (using the cost of a passenger-hour, car-hour, and other factors) for estimating the economic costs that the user (driver or passenger) must bear in the form of additional time costs as a result of the unreliable functioning of the transport system.
The existing methods of justifying the need to allocate lanes for urban passenger transport are mainly based on indicators of traffic intensity and traffic capacity, as well as the values of passenger flow on a given section of the road network.
The considered methods do not fully characterize the level of existing delays. That is, these methods do not take into account the additional costs of waiting time associated with the regulation of traffic on
a given section of the city's road network, which combines not only indicators of intensity and throughput, but also the parameters of traffic light regulation and the length of the queue. Also, the above methods do not take into account the share of passenger traffic in the total number of road users.

3. Materials and methods

To substantiate the need to allocate lanes for the movement of urban passenger transport, let us consider the section of the route network, along which vehicles move freely (without having priority), including the rolling stock of urban passenger transport.

It is not technically possible to designate a lane for urban traffic on roads with less than two lanes in one direction; therefore, the following condition must be met:

\[ n \geq 2 \]  

(3)

where \( n \) is the number of lanes in one direction on the stretch under consideration.

The movement of the rolling stock of urban passenger transport on the considered section of the route network in the general flow is considered. The movement of transport is associated with the limitation of the value of its throughput. The level of the throughput of urban passenger transport, which is not related to the technical operations of embarking and disembarking passengers, is mainly limited by the throughput of intersections of the city's road network and, as a rule, is associated with the indicator of traffic regulation delay. The delay indicator combines such indicators as the traffic intensity and throughput of the considered section of the road network, the length of the queue and the parameters of traffic light regulation. To ensure high speed of communication and increase the attractiveness of urban mass passenger transport, it is necessary to ensure an acceptable minimum level of delay.

The parameters of the movement of vehicles through the regulated intersection of the road network entirely depend on the traffic light regulation mode. That is, they depend on the duration of the regulation cycle, as well as on the duration of its constituent cycles, phases and the order of their alternation. In this case, the main movement of vehicles through the intersection is carried out during the period of the burning of the permitting traffic signal.

It should be noted that the beginning of the movement of vehicles at the moment when the permission signal of the traffic light comes on occurs with a certain delay (start delay) associated with the acceleration of vehicles and the necessary response time of the driver to the change of traffic signals. In this case, the traffic intensity of the flow of vehicles gradually increases to a value equal to the throughput of the considered direction [23,24,25,26].

At the moment when the prohibiting traffic light comes on, vehicles that do not have the technical ability to stop at the stop line continue their movement through the intersection, forming a "breakthrough" time.

Thus, the movement of vehicles through the regulated intersection of the road network begins somewhat later than the beginning of the burning of the permitting signal of the traffic light and ends during the period of the burning of the prohibited signal of the traffic light. The time of the actual implementation of the movement of vehicles through the intersection of the road network can be called the effective duration of the phase.

Consequently, the maximum (minimum) acceptable level of delay time for urban passenger transport, including when driving in free conditions, should be equal to the duration of the regulation cycle minus the time of the effective duration of the phase

\[ Z = C - g_e \]  

(4)

where: \( Z \) is delay time of urban passenger transport, sec;
\( C \) is the duration of the regulation cycle, sec;
\( g_e \) is effective phase duration, sec.
As practice shows, there are sections of the route network, traffic delays on which are acceptable or become acceptable at certain hours of the day. It is not uncommon for such tracks to have dedicated lanes intended for the movement of urban passenger transport. The presence of restriction (4) casts doubt on the need to allocate such lanes on the considered sections of the city's route network.

In the city of Krasnoyarsk, some stretches are part of only one route of urban passenger transport, where dedicated lanes operate to ensure its priority. The efficiency of work and the need to identify such bands are questionable. Ensuring the priority of urban passenger transport should be inextricably linked with the size of the passenger flow moving on the considered section of the road network. In this case, the size of the passenger flow should be commensurate with the number of participants moving in a free (without prioritization) flow along the maximum loaded traffic lane and moving in the same direction. Therefore, the following inequality is real:

\[ Q \geq v_{cn} \cdot q_{mc}, \quad (5) \]

where: 
- \( Q \) – the number of passengers traveling along the section under consideration per unit of time (for example, per hour), pass / hour;
- \( v_{cn} \) – the intensity of the free flow per unit of time along the maximum loaded traffic lane (for example, per hour), given units / hour;
- \( q_{mc} \) – the average number of passengers in a vehicle from a free flow of traffic (excluding urban passenger transport), pass.

Thus, taking into account the above, it is possible to formulate the following conditions, the presence of which determine the objective need to ensure the priority of public urban passenger transport on the considered section of the city's road network:

\[ \begin{align*}
&n \geq 2; \\
&Z > C - g_c; \\
&Q \geq v_{cn} \cdot q_{mc}. 
\end{align*} \quad (6) \]

In the city of Krasnoyarsk, the route network spans were examined for their compliance with the conditions of restrictions (6). On the hauls of the route network with more than two lanes in one direction, at different times of the day, the following was recorded:

1. The level of transport delay, the duration of the regulation cycle and its components. For determine the level of delay, it is necessary to take into account vehicles arriving at the intersection of carriageways, but not having time to cross it because of the need to stop, and the total number of vehicles arriving at the intersection.

2. The power of the passenger flow was determined by the eye method directly on the stretch of the route network.

3. Traffic intensity and a number of passengers in the total traffic.

The examination revealed:

1. About 35% of the routes in the route network have dedicated lanes for the movement of urban passenger transport. The main number of spans with dedicated lanes appeared in preparation for the Universiade.

2. About 10% of the routes of the route network with dedicated lanes for the movement of route vehicles do not meet the requirements of restrictions (4). Consequently, the need to identify such bands is questionable.

3. About 5% of the routes in the route network with dedicated lanes for the movement of route vehicles do not meet the requirements of restrictions (5).
4. In between-peak and evening hours, the number of routes in the route network with dedicated lanes for the movement of route vehicles can be reduced (up to 45%).

5. About 6% of the runs of the city's route network, at peak hours, meet the conditions of restrictions (6). Therefore, they require the device of dedicated lanes for the movement of urban passenger transport.

Thus, the results of the survey carried out confirm the need to take into account conditions (6) when making decisions on the need to allocate separate lanes for the movement of urban passenger transport.

4. Conclusion
The throughput of urban passenger transport lines, not related to the process of embarking and disembarking passengers, is mostly limited by the throughput of intersections of the city's road network, which is significantly influenced by the parameters of random processes of vehicle arrival.

The proposed mathematical model forms the necessary conditions, the strict fulfillment of which determines the need to ensure the priority of public urban passenger transport on the considered section of the city's road network. The necessary conditions are based on such indicators as the level of traffic delay and the share of the passenger flow in the total flow of traffic participants.

The traffic delay level combines such indicators as traffic intensity and capacity of the considered section of the road network, queue length and regulation parameters. The amount of passenger flow is compared with the amount of the flow of participants moving in free mode.

Thus, the proposed model makes it possible to determine the rationality of the allocation of separate lanes, traffic for public transport under the level of traffic in the city's road network. This study, in turn, can become the basis for the algorithm for the operation of interactive signs that regulate traffic on a given stretch of the city's road network.

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