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Evaluation effectiveness of solutions to improve mobility in cities

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Abstract: The article proposes a methodology for developing efficiency conditions when developing some solutions related to increasing urban mobility. An example of the conditions for applying and testing the coordinated regulation method used to ensure uninterrupted traffic on main streets, taking into account possible delays in traffic flows on intersecting streets, is given. The procedure for determining the maximum values of the flow and intensity of bus traffic is given in order to maintain the speed of traffic flows within a certain limit when organizing dedicated bus lanes. Simulation experiments were used to test the efficiency of creating bus lanes and a green wave based on the proposed methodology. Micromodels were created using the PTV VISSIM program.
Keywords: mobility, urban transport, bus lane, coordinated regulation, delay

1. Introduction

Ensuring the quality of life of the city population largely depends on the functioning of the urban transport infrastructure. The main tasks facing transport organizations are to ensure the implementation of trips for various purposes in a short time and with the appropriate convenience. Of course, pedestrian and bicycle paths that promote a healthy lifestyle are important, and their development requires a favorable infrastructure. It is necessary to ensure the interconnection of public transport and take organizational measures to reduce the time lost in traffic flows. However, solutions to ensure mobility require a comprehensive implementation of all provided measures. As indicators of the quality of mobility in cities, the population primarily perceives travel time, comfort and traffic safety [1]. Reducing and minimizing time losses in traffic flows are the main goals of improving mobility in cities. Therefore, it is necessary to develop measures aimed at studying and reducing the time lost by road users. When analyzing mobility models of European cities, the following solutions are proposed to ensure sustainable and environmentally friendly urban mobility [2]:

- increase in the number and coordination of bicycle paths;
- development of public transport systems;
- expansion of bicycle and pedestrian paths;
- creation of bicycle sharing systems;
- improvement of connections between the city center and its outskirts by means of bus, tram and metro lines;
- promotion of the use of alternative modes of transport;
- restriction of car access to the central parts of the city;
- increase of pedestrian zones;

Kijewska et al., analyzing mobility problems in the cities of Belo Horizonte, Brazil, and Szczecin, Poland, propose organizing activities in the following three directions [3]:

- increasing and improving the accessibility of public transport;
- more efficient organization of freight transportation within the city;
- organization of transportation in accordance with the mobility of residents.

Papadakis and his co-authors studied the practices implemented in various cities in order to ensure mobility in cities. The authors noted that it is important to implement strategies to improve public transport, reduce the use of private cars and create more pedestrian and bicycle paths to increase mobility in cities [4].

Literature review. One of the most common measures to reduce vehicle travel time in cities is the "green wave" regime, which involves coordinating traffic light modes on city streets, as well as creating special bus lanes to reduce passenger travel time. In many cases, these solutions can cause certain side effects. For example, the introduction of a "green wave" leads to an increase in delay time due to the expansion of the prohibiting signal on intersecting streets. The creation of bus lanes reduces the area intended for vehicle movement, which leads to additional delays in traffic flows.

There are various approaches to studying traffic delays. In his study on the analysis of traffic delays at signalized intersections, Abdurakhmanov proposed optimizing the traffic light modes at signalized intersections to reduce traffic flow delays [5].

Li and his co-authors studied the impact of congestion on traffic flow during vehicle deceleration on a two-lane street and road network. The authors proposed a new model that takes into account congestion during braking. The proposed model provides a more realistic description of the traffic flow by taking into account the difference between the current vehicle density and the density that occurs during deceleration [6].

Bashar et al. analyzed the traffic delay times on the Phulbarigate–Daulatpur Highway in Bangladesh and investigated the causes of delays during and off-peak hours. They found that vehicles traveling at low speeds (e.g., 10 km/h) increase the overall deceleration and reduce the road capacity [7].

To reduce traffic delays, Royko et al. tested the effectiveness of coordinated traffic signal control using the PTV Vissim simulation program. The authors showed that coordinated control organized on the considered street ensures smooth movement of vehicles at successive intersections, significantly reducing the overall delay time [8].

Dhinakaran estimated the traffic delay times at controlled intersections in Tamil Nadu, India, using the Webster and Highway Capacity Manual (HCM) models. The

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author found that the Webster and HCM models are ineffective for mixed traffic flows. A new approach to delay estimation for mixed traffic flows is presented [9].

2. Research methodology

The paper proposes to compare the proposed solutions for improving mobility with the existing or previously used option in terms of total time costs. A mathematical model for estimating the total time costs is proposed when applying coordinated regulation on a main street and when creating a bus line.

In real conditions, it is necessary to estimate the total time losses on intersecting streets and compare options depending on the duration of the prohibiting signal and the intensity of the traffic flow. The total delay time of all vehicles on main and intersecting streets on a street with a coordinated arrangement can be determined using traditional analytical methods. However, it is more appropriate to obtain results that are more consistent with real conditions using a simulation model based on data taken from a real street and road network. The experience of using the PTV VISSIM modeling program for studying, modeling and testing traffic flows is widespread [10,11,12,13]. Figure 1 shows a test image of the simulation model of coordinated traffic control on Bakikhanov Street, one of the main streets of Baku, created using the PTV VISSIM program. Traffic light rules have been introduced at 7 intersections of the street.

Figure 1. Example of 3D tests of the simulation model of traffic flow at intersections of Bakikhanov Street

As can be seen from Figure 1, serious queues arise on almost all streets intersecting with the main street. The scheme of the "green wave" mode in one direction on the main street, created using PTV VISSIM, is shown in Figure 2.

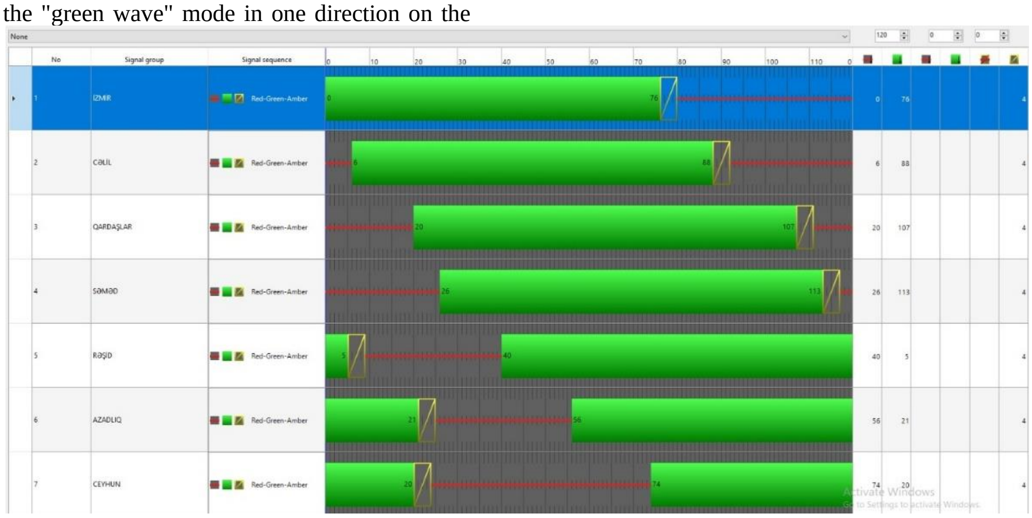

Figure 2. Coordinated control schedule in the PTV VISSIM

After the implementation of coordinated regulation on the main (trunk) street, the cost of traffic delays on intersecting streets changes. If this change is in the direction of increase, and the value of traffic intensity in the directions on intersecting streets is large, then the total amount of lost time may be greater than before. Therefore, the total values of delay time on main (trunk) and intersecting streets must satisfy the following condition:

$$\sum d_{agv} < \sum d_{bgv} \quad (1)$$

Where $\sum d_{bgv}$ and $\sum d_{agv}$ - are the total delay times of all vehicles on the main and intersecting streets before and after the application of the agreed regulation, respectively.

$$\sum d_{agv} = \sum_j^m \sum_{i=1}^n N_{vi} d_{ibgv}$$
$$\sum d_{agv} = \sum_j^m \sum_{i=1}^n N_{vi} d_{iagv}; \quad (2)$$

Where d_{ibgv}, d_{iagv} - the time of vehicle delays at the stop line i before and after the application of the corresponding coordinated regulation; N_{vi} - number of vehicles in the direction i.

As a result of the application of isolated and coordinated control on the street under consideration, using simulation tests, the total amount of traffic delays on the main and intersecting streets was 139 and 149.6 hours, respectively. It follows that the cost of total time loss increased with the

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introduction of coordinated control as a result of the increase in delay time on intersecting streets.

When creating special lanes for public transport, the time lost by vehicles in the general traffic flow increases. This increase takes on different values depending on the number of traffic lanes [14]. Figure 3 schematically shows the situation after the introduction of a special traffic lane on a street with a three-lane roadway.

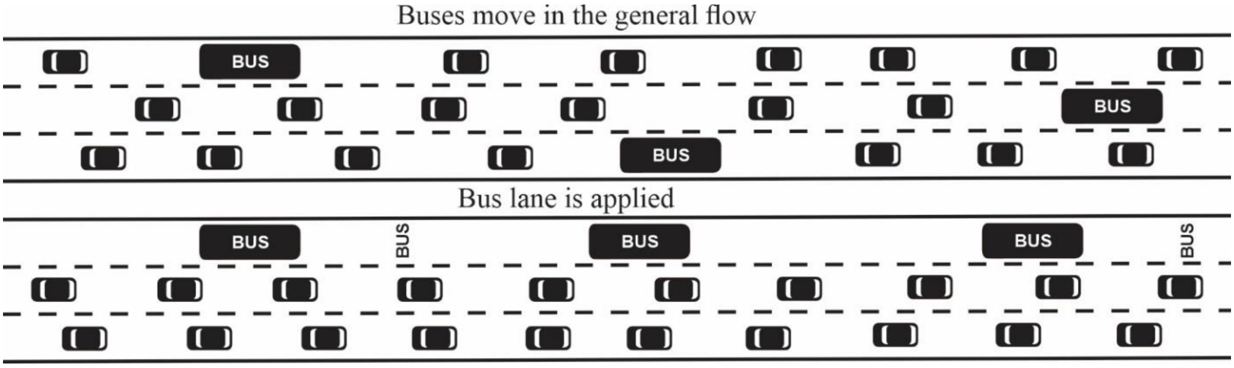

Figure 3. Changes in traffic scheme after the introduction of bus lanes

The efficiency condition for bus lanes, based on the time lost in creating bus lanes, can be expressed as follows:

$$\sum t_{losaf} < \sum t_{losbef} \quad (3)$$

Where $\sum t_{losaf}$ and $\sum t_{losbef}$- are the total time lost by road users before and after the creation of the bus lane, respectively.

$$\sum t_{losbef} = \overline{t_{jgf-bef}}\left(n_{bef} + \sum_{r=1}^{m} q_r \gamma_{rj}\right) \quad (4)$$

$$\sum t_{losaf} = \left(n_{af}\overline{t_{jgf-af}} + \overline{t_{busj}} \sum_{r=1}^{m} q_r \gamma_{rj}\right) \quad (5)$$

Where $\overline{t_{jgf-bef}}; \overline{t_{jgf-af}}$- the travel time of vehicles on the general flow through the section j in question before and after the creating bus lane respectively; $n_{bef}; n_{af}$ - the number of vehicles traveling in the general flow through the section j in case before and after the creating bus lane respectively; $\overline{t_{busj}}$- travel time of buses through the section j; γ_{rj}- capacity factor of bus r in the section j.

Measurements on the street under consideration show that increasing the delay time on narrow streets does not reduce the overall time losses, but on the contrary increases them. In tests conducted on a street section 800 meters long (with a traffic flow intensity of 2200 NV/h and an hourly bus frequency of 160 buses/h), the time it takes to travel the road section was determined based on the values determined by live observation in real street conditions. The maximum speed was taken to be 50 km/h in accordance with local traffic organization conditions. A comparison of the values obtained before and after the introduction of the bus lane using a micromodel created in PTV VISSIM shows that the time spent per traveler decreases on 2-, 3- and 4-lane roads (from 114 seconds to 82 seconds, from 79 seconds to 71 seconds and from 73 seconds to 67 seconds, respectively) [15].

If it is necessary to maintain the speed of the traffic flow at a certain level (for example, to prevent violation of the "green wave" mode), it is necessary to check the efficiency of the implementation of the dedicated bus lane, based on the condition of maintaining this speed limit. As an example, we will create a regression equation showing the dependence of the speed on the intensity of the traffic flow before and after the introduction of the bus lane, using the indicators obtained as a result of simulation experiments on a three-lane road. The permitted speed on the street is 50 km / h. The effect of the intensity of the traffic flow and the frequency of bus arrivals changes according to the following expression when buses move in the general flow:

$$V = 62.9 - 0.0015N_{veh} + 0.067N_{bus}, R^2 = 82{,}13 \quad (5)$$

Where N_{veh}- is vehicle traffic intensity, veh/h; N_{bus} - is bus ariiving frequency, bus/h.

When buses move along a dedicated lane, the speed of the general flow will not depend on the frequency of buses, since the flow is isolated from buses. However, the number of traffic lanes will be reduced by one lane. In this case, the speed of movement in the mixed flow changes according to the following expression depending on the traffic intensity:

$$V = 60.1 - 0.0083N_{veh}, R^2 = 95{,}74 \quad (6)$$

Using the obtained dependencies, it is possible to check the efficiency of introducing a dedicated bus lane, subject to maintaining the speed limit, based on the traffic intensity and frequency of bus arrivals.

3. Conclusion

It is necessary to evaluate in advance the consequences of the proposed measures to improve population mobility. There are various analytical methods for assessing the time of delays associated with the organization of road traffic in cities. However, it is possible to conduct an assessment in a shorter time and more accurately using simulation models of traffic organization based on real values (intensity, density, speed, etc.) taken from the street and road network.

Coordinated regulation aimed at ensuring the smooth movement of traffic flows on city streets can lead to an increase in the overall time losses on neighboring streets. Although the introduction of bus lanes reduces the time spent by buses on the route, it can lead to an increase in delays for vehicles moving along this street. Therefore, these solutions should be considered appropriate only if the overall time losses, when implemented, are less than the previous options for organizing traffic. Thus, the proposed approach will allow us to preliminarily determine the effectiveness of the measures under consideration.

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