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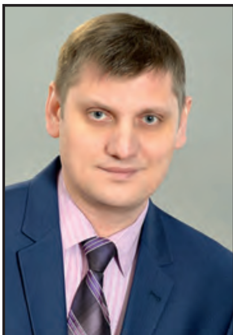
Increase in Speed of Regular Urban Bus Traffic



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ABSTRACT

The article outlines the currently relevant directions for increasing the efficiency of passenger transportation by urban transport, achievable through using modern digital technologies for monitoring and controlling congestion of the road network, traffic management, and assessing reliability of the transportation process.

The objective of the study was to develop theoretical base and practical recommendations for increasing speed of traffic on regular urban bus routes during periods of high load of the urban road network using alternate roads.

Theoretical studies were based on the analysis of scientific and regulatory sources, and on the system analysis of transportation processes. Experimental studies were carried out in laboratory and road conditions using mathematical modelling, methods of mathematical statistics, technical, economic and system analysis of transportation processes, analysis of passenger flows, field observations.

The dependences of the flow rate of vehicles on traffic intensity, technical speed of buses on alternate roads on the flow rate of fixed-route vehicles are obtained. The economic effect resulting from implementation of recommendations was calculated for the conditions of the city of Magnitogorsk, since redirecting the buses to alternate roads during peak load periods for road network allows to increase their route speed by 7 km/h and hence to reduce the need in bus fleet by 2 units, obtaining the target economic effect.

Keywords: *transport, urban public transport, urban road network, regular bus route, traffic speed.*

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Background. Improving the efficiency of passenger transportation by urban transport is an important socio-economic problem. One of the directions for solving this problem, which is currently being actively discussed by the experts, is to accelerate the flow of fixed-route vehicles, which can increase traffic speed. Modern domestic and foreign scientific sources offer methodological recommendations aimed at accelerating the flow of urban transport vehicles through the use of navigation dispatch systems, digital technologies for assessing traffic congestion, individual means of mobile communication to assess the state of traffic and passenger time losses along the route [1–4].

A large number of works are devoted to organization of traffic in order to increase the capacity of the urban road network, including a regular route network of urban transport. For example, on the basis of analytical methods, the authors of [5–7] offer recommendations on organization of work of stopovers at regular urban transport routes, managing the duration of the traffic flow at controlled intersections, and optimizing route networks of urban passenger transport.

Attention should also be paid to works [8; 9], which propose a methodological basis for assessing reliability of passenger transportation by urban transport. The recommendations proposed by the authors make it possible to quantitatively substantiate such a parameter of quality of public transport services as reliability, which in most cases is assessed by qualitative characteristics.

Despite the comprehensive study of the problem under consideration, implementation of the proposed methods for accelerating fixed-route vehicles requires refinement and tuning to individual characteristics of the planning decisions of the road network of a particular city, often missing undeveloped areas for road construction.

Therefore, the *objective* of this study is to develop of a theoretical base and practical recommendations to increase the traffic speed on regular bus routes of urban transport during periods of high load of the urban road network through the use of alternate roads. The development of the theoretical base, which is the scientific novelty of the study, consists in establishing the dependencies of the vehicle flow rate on traffic intensity, as well as of the technical speed of the bus along additional roads on the flow rate of fixed-route vehicles. The practical significance of the work lies in development of practical recommendations for increasing the speed of traffic at the example of regular route network of the city of Magnitogorsk.

The *methods* applied are widely used by other researchers. The analysis of scientific and regulatory sources made it possible to identify the maturity of the study of the problem of increasing the efficiency of passenger transportation by urban transport, as well as to identify the existing methods for calculating the speed of the traffic flow, to formulate the objective of this study. A systematic analysis of transport processes made it possible to establish the effect of traffic congestion on speed of the traffic flow.

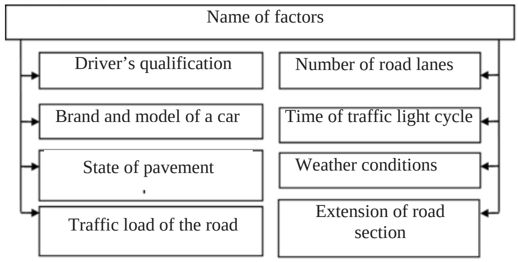
Mathematical modelling ensured performance of multiple calculations of speed of the traffic flow at various driving modes of vehicles at regulated intersections, considering the different levels of traffic load on the road network. Based on the simulation results and using statistical analysis, the desired dependencies were constructed, reliability of approximation was estimated, and the regression equations were established.

The initial data for the calculations performed, as well as for establishing critical sections of the road network of the city of Magnitogorsk in terms of load, were obtained from field observations of traffic flows on urban roads, as well as by direct calculation of passenger traffic correspondence on regular urban transport routes. The feasibility study made it possible to justify the practical implementation of methodological tools to increase the speed of traffic on regular bus routes during periods of high load of the city's road network using alternate roads.

Results.

The effect of reducing the cost of transporting passengers when buses are sent to alternate roads during the load of the road network is achieved by reducing the number of buses on the route to perform transportation at a specified traffic interval as a result of an increase in the traffic speed. Traffic speed is determined by the flow rate of vehicles, the value of which is influenced by the factors shown in Pic. 1.

A wide variety of methods for calculating the flow rate of vehicles can be found in scientific



Pic. 1. Factors influencing transport flow speed.

and educational sources. For example, in [10, p. 6] it is proposed to calculate the average speed by the formula:

$$V_{av.} = \frac{l_{\text{sec.}}}{t_c^{av.}}, \qquad (1)$$

where $l_{sec.}$ is length of the road segment, km;

$t_c^{av.}$ is average travel time needed for cars to pass through the segment, h.

The travel time of a car passing through the segment includes delays in movement due to interruptions in flow due to regulatory signals or congestion:

$$t_c = t_a + t_{\text{mov}} + t_s + t_w, \qquad (2)$$

where t_a is acceleration time of the vehicle to the maximum permitted speed, sec;

t_{mov} is vehicle travel time within the segment with the maximum permitted speed, sec;

t_s is stop time, sec;

t_w is waiting time because of the traffic congestion at the intersection, sec.

The acceleration time of the vehicle to the maximum permitted speed is a reference value, the remaining components of formula (2) are calculated. The vehicle travel time in the area with the maximum permitted speed is determined by the formula:

$$t_{\text{mov}} = \frac{l_{\text{sec}} - l_{\text{con}} - l_s}{V_{\max}}, \qquad (3)$$

where $l_{con.}$ is length of congestion in front of the intersection, m;

l_s is car stopping distance, m;

V_{max} is maximum permitted vehicle speed in the section, m/s.

The stopping distance of the car is calculated by the formula:

$$l_s = \left(t_r + t_t + 0{,}5 \bullet t_i\right) \bullet V_0 + \frac{V_0^2 \bullet K_e}{2 \bullet g \bullet \phi_x}, \qquad (4)$$

where t_r is driver reaction time, s;

t_t is triggering time of the brake system, s;

t_i is increase time of braking forces, s;

V_0 is initial braking speed, km/h;

K_e is braking efficiency coefficient;

g is acceleration of gravity, m/s^2;

φ_x is coefficient of longitudinal adhesion of wheels of the car with the road.

Stopping time is time from the moment when the driver noticed an obstacle to a complete stop of the car, and it is determined by the following formula:

$$t_s = t_r + t_t + 0{,}5 \bullet t_{i0} + \frac{V_0 \bullet K_e}{g \bullet \phi_x}. \qquad (5)$$

The waiting time for traffic congestion during the time of action of the traffic light at the intersection is determined by the formula:

$$t_w = I_1 + \left(n_{\text{acc}} - 1\right) \bullet I_p + n_{\max} \bullet I_{\max}, \qquad (6)$$

where I_1 is duration of the stop-line crossing by the first vehicle after the start of movement, sec;

n_{acc} is number of vehicles that cross the stop line during acceleration to the maximum permissible speed from the moment the enable signal of the traffic light is turned on;

I_p is interval between the front bumpers of vehicles when passing the stop line during acceleration of the flow to the maximum permissible speed;

n_{max} is number of vehicles that cross the stop line at the maximum permissible speed from the moment the enable signal of the traffic light is turned;

I_{max} is interval between the front bumpers of vehicles when passing the stop line at the maximum permissible speed, sec.

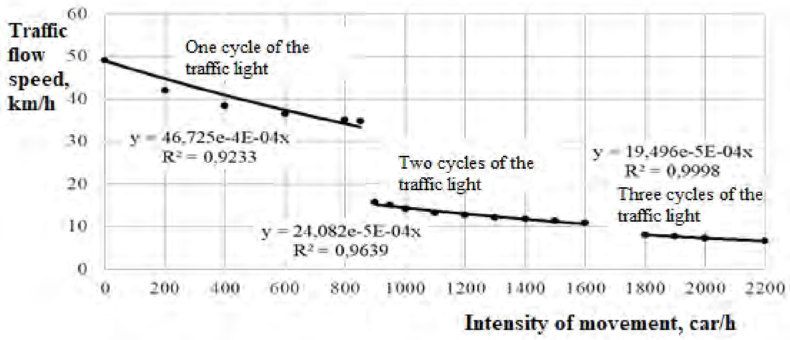
Only the time period when the green traffic light is on is available for movement. The presence of a traffic lights' permitting signal at the moment the vehicle approaches the intersection will determine the flow rate of the vehicles. Therefore, in the calculations, four modes of passing by vehicles of regulated intersections were considered. The flow rate of vehicles is proposed to be considered as the average value of the vehicle speed of the intersection under four modes.

The first mode: movement from green light to green light whilst there is or there is no traffic jam at the next intersection. The vehicle enters the section with a working green traffic light (initial speed of 60 km/h) and arrives at the next intersection with traffic jam when the green traffic light comes on, or passes that intersection if there is no traffic jam at this time.

Table 1

Options of calculation of speed of flow of vehicles at various modes through regulated intersections

First mode: movement from the green light to the green light (there is or there is no traffic jam at the next intersection)	
Without traffic jam (intensity of movement at the segment is less than the transit capacity of the segment)	With traffic jam (intensity of movement at the segment is higher than the transit capacity of the segment)
$V_1 = \frac{l_{sec}}{t_{mov}}$,	$V_1 = \frac{l_{sec}}{t_{mov} + t_s + t_w}$.
Second mode: movement from the red light to the red light (there is a traffic jam)	
$V_2 = \frac{l_{sec}}{t_r + t_{mov} + t_s + t_w}$.	
Third mode: movement from the red light to the green light (there is or there is no traffic jam at the next intersection)	
Without traffic jam (intensity of movement at the segment is less than the transit capacity of the segment)	With traffic jam (intensity of movement at the segment is higher than the transit capacity of the segment)
$V_3 = \frac{l_{sec}}{t_r + t_{mov}}$,	$V_3 = \frac{l_{sec}}{t_r + t_{mov} + t_s + t_w}$.
Forth mode: movement from the green light to the red light (there is a traffic jam at the next intersection)	
$V_4 = \frac{l_{sec}}{t_{mov} + t_s + t_w}$.	



Pic. 2. Dependence of traffic flow speed on intensity of movement.

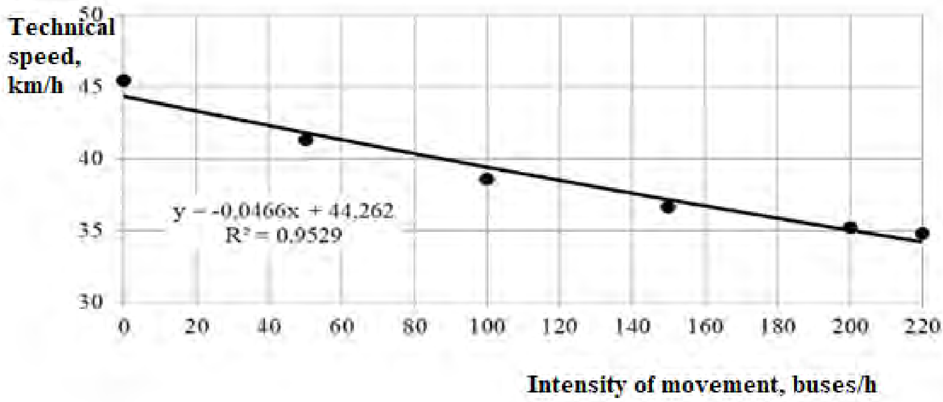
The second mode: movement from a red light to a red light with a traffic jam. The vehicle enters the section after waiting for the green traffic light to turn on (initial speed 0 km/h) and arrives at the next intersection at which a traffic jam was formed due to waiting for the traffic permitting signal.

The third mode: movement from a red light to a green light whilst there is or there is no traffic jam at the next intersection. The vehicle enters the section after waiting for the green traffic light to turn on (initial speed 0 km/h) and arrives at the next intersection with traffic jam when the green traffic light comes on, or passes that intersection if there is no traffic jam at this time.

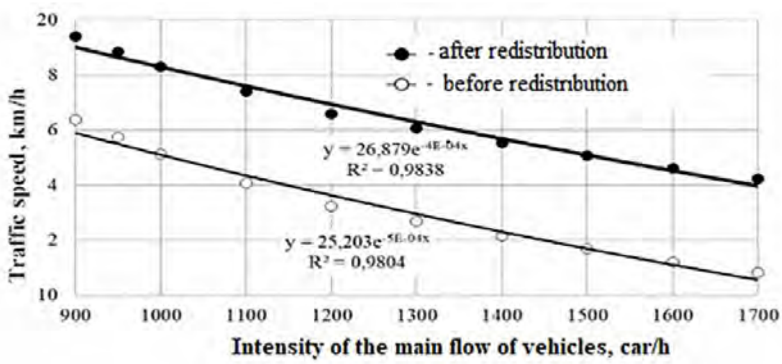
The fourth mode: movement from a green light to a red light when there is traffic jam at the next intersection. The vehicle enters the section with a working green traffic light (initial speed of 60 km/h) and reaches the next intersection where a traffic jam has formed due to waiting for the traffic-permitting signal.

Options for calculating the speed of the traffic flow for various modes of travel through signal-controlled intersections are shown in Table 1.

Through calculations using the methodology shown in Table 1, the dependence of vehicle flow rate on traffic intensity was obtained for three levels of load of a road network segment



Pic. 3. Dependence of the technical speed of buses on alternate road on the flow rate of fixed-route vehicles.



Pic. 4. Change of average speed of buses when they are directed to alternate roads of the road network of Magnitogorsk.

when a vehicle overcomes a traffic jam in front of a signal-controlled intersection during one, two, and three traffic lights cycles, respectively (Pic. 2).

Besides, based on mathematical modelling, the dependence of the technical speed of buses along the alternate roads of the city road network during its high load on the flow rate of fixed-route vehicles was established (Pic. 3).

The dependence was obtained for signal-controlled traffic conditions of return of fixed-route vehicles from an alternate road to the main segment of the city road network after a detour of a traffic jam. The found dependencies are necessary for calculating the traffic speed, the required number of buses on the route and the resulting economic effect from implementation of recommendations on the direction of fixed-route transport to alternate roads during the load of the road network.

Traffic speed also depends on the planning decisions of the urban road network. These development decisions are individual for each municipality. In this work, an analysis of the road network of the city of Magnitogorsk was carried out in terms of determining the places of possible acceleration of the flow of fixed-route vehicles due to its redistribution to alternate roads.

In Magnitogorsk, alternate roads make part of the road network in the southern part of Karl Marx and Lenin Avenues, as well as in the central part of Truda Street and 50-letiya Magnitki Street. Routes of regular bus routes run through these sections and in these places it is possible to accelerate the flow of fixed-route vehicles. According to the results of the analysis and calculations, it was found that redistribution of fixed-route buses to alternate roads increases the traffic speed on regular bus routes by an average of 4 km/h (Pic. 4).

Feasibility study

The rationale for practical implementation of methodological tools to increase the traffic speed on regular bus routes by directing fixed-route transportation to alternate roads during the load periods of the road network was made at the

Table 2

Calculation results of intensity of traffic flow on Karl Marx Avenue, car/h [11]

Sections of the road network	Periods of the day								
	9:00–12:00			12:00–15:00			15:00–18:00		
	Forward direction	Backward direction	Sum	Forward direction	Backward direction	Sum	Forward direction	Backward direction	Sum
1. Vokzalnaya–Moskovskaya	438	330	768	300	240	540	384	342	726
2. Moskovskaya–Pervomaiskaya	600	354	954	468	360	828	534	372	906
3. Pervomaiskaya–Uralskaya	624	468	1092	570	474	1044	690	468	1158
4. Uralskaya–Komsomolskaya	588	594	1182	450	642	1092	642	582	1224
5.Komsomolskaya–Leningradskayая	630	720	1350	702	732	1434	786	636	1422
6. Leningradskaya–Tatishcheva	513	684	1197	960	906	1866	768	720	1488
7. Tatishcheva–Gagarina	510	726	1236	774	696	1470	786	714	1500
8. Gagarina–im. Gazety «Pravda»	536	678	1214	1014	942	1956	906	882	1788
9. im. Gazety «Pravda»–Druzhby	576	894	1470	954	882	1836	960	924	1884
10. Druzhby–magazin «Vesna»	551	720	1271	816	918	1734	864	900	1764
11. Magazin Vesna–Gryaznova	574	774	1348	966	828	1794	960	870	1830
12. Gryaznova–Sovetskoi Armii	554	1014	1568	1074	948	2022	1038	978	2016
13.Sovetskoi Armii-Stalevarov	1256	1044	2300	1348	710	2058	1752	645	2397,855
14. Stalevarov–Zavenyagina	1200	1065	2265	1300	736	2036	1690	669	2359,091
15. Zavenyagina–ost. Engelsa	968	650	1618	1276	600	1876	1659	545	2204,255
16. st. Engelsa–Borisa Ruchieva	960	680	1640	1210	612	1822	1573	556	2129,364
17. Borisa Ruchieva–Truda	856	920	1776	972	952	1924	1264	865	2129,055
18. Truda-50-letiya Magnitki	580	464	1044	720	692	1412	936	629	1565,091
19. 50-letia Magnitki–Zeleniy Log	512	532	1044	724	612	1336	941	556	1497,564
Total:	13026	13311	26337	16598	13482	30080	19133	12855	31988

example of bus route No. 33 of Magnitogorsk. The bus route under consideration connects the southern areas of the city with its southeastern outskirts in the left-bank part. The route is of pendulum type. Its length in the forward and reverse directions is 36,2 km. GAZ-322132 and Citroen Jumper buses are operated on the route.

Analysis of the load of urban road network sections during the day along which the alternate route No. 33 runs allows us to determine the critical section on Karl Marx Avenue (Table 2).

Critical segment is a section of the Karl Marx avenue from intersection with Stalevarov Street to intersection with Truda Street where, during the peak period of the day from 15:00 to 18:00, the average flow speed of vehicles decreases to 11 km/h, which leads to formation of traffic jams at the intersections and an increase in the transit time for passengers of fixed-route transport. During these periods of the day, it is advisable to direct the buses of the considered route from the main road to the alternate roads located along Karl Marx Avenue within the sections:

• from Stalevarov Street to Zavenyagina Street;

• from Zavegyagina Street to Engelsa st.;

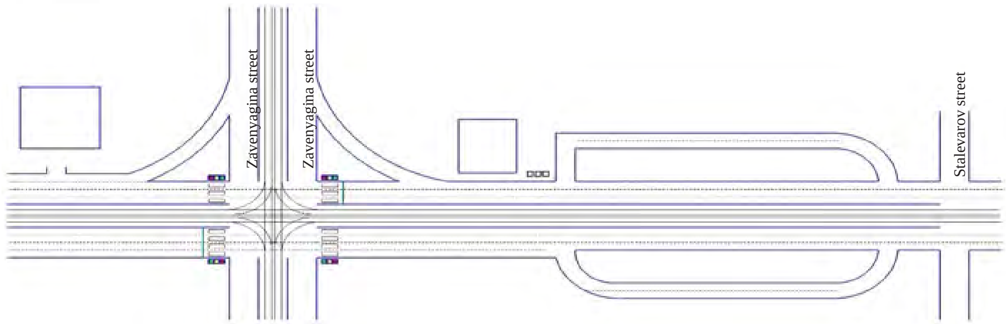
• from Engelsa ost. to Borisa Ruchieva Street;

• from Borisa Ruchieva Street to Truda Street.

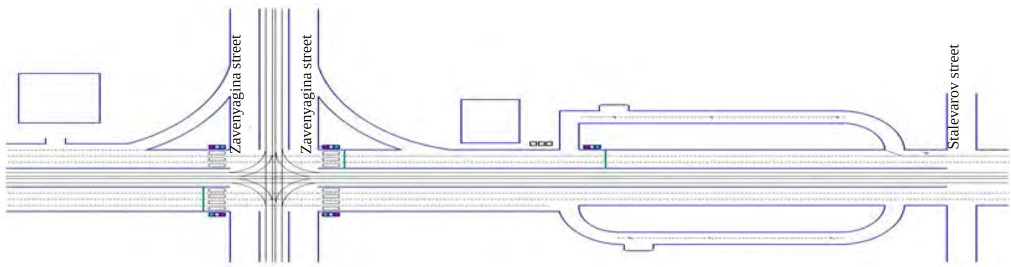
Fixed-route vehicles traffic on alternate roads requires to organize traffic lights to regulate the return of buses from alternate roads to the main road network. This involves costs of acquisition and installation of traffic lights, the installation locations of which are shown in the diagrams (Pics. 5–7). In addition, it will be necessary to transfer the existing traffic light unit from Zory Urala stop to the intersection of the alternate road with the main avenue at the section Stalevarov Street–Zavenyagina Street. This is necessary in order to pass the bus from the alternate road to the main road without delaying the flow of vehicles.

The results of feasibility study of the existing and proposed options for organizing the operation of bus route No. 33 are shown in Table 3.

The calculations made it possible to establish that the directing of buses during the periods of peak load of sections in the southern part of Karla Marx Avenue to alternate roads from 15:00 to 18:00 increases the traffic speed on the bus route under consideration from 11 km/h to 18 km/h. The time to travel through the section under consideration is reduced from 15 minutes to 9 minutes. Such a measure will exclude an increase in demand for buses on the

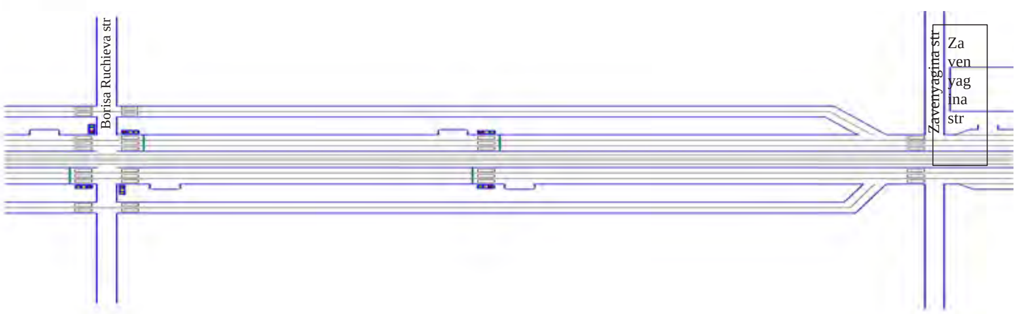


a) Existing option

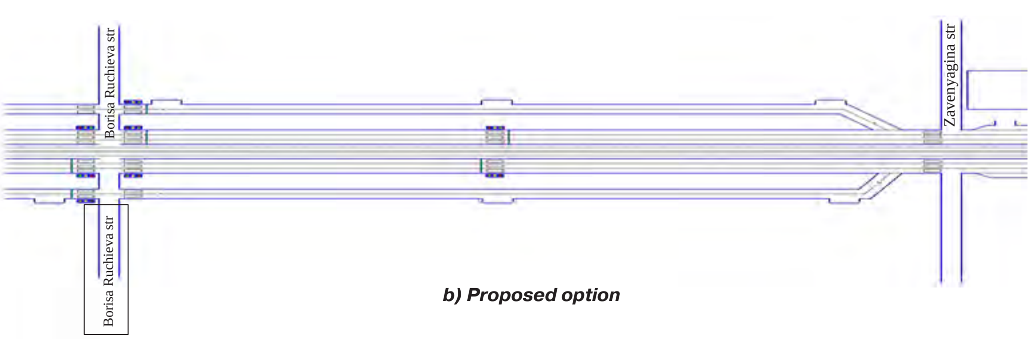


b) Proposed option

Pic. 5. Schemes of organization of road traffic in Magnitogorsk along Karl Marx Avenue from Stelavarov street to Zavenyagina street.

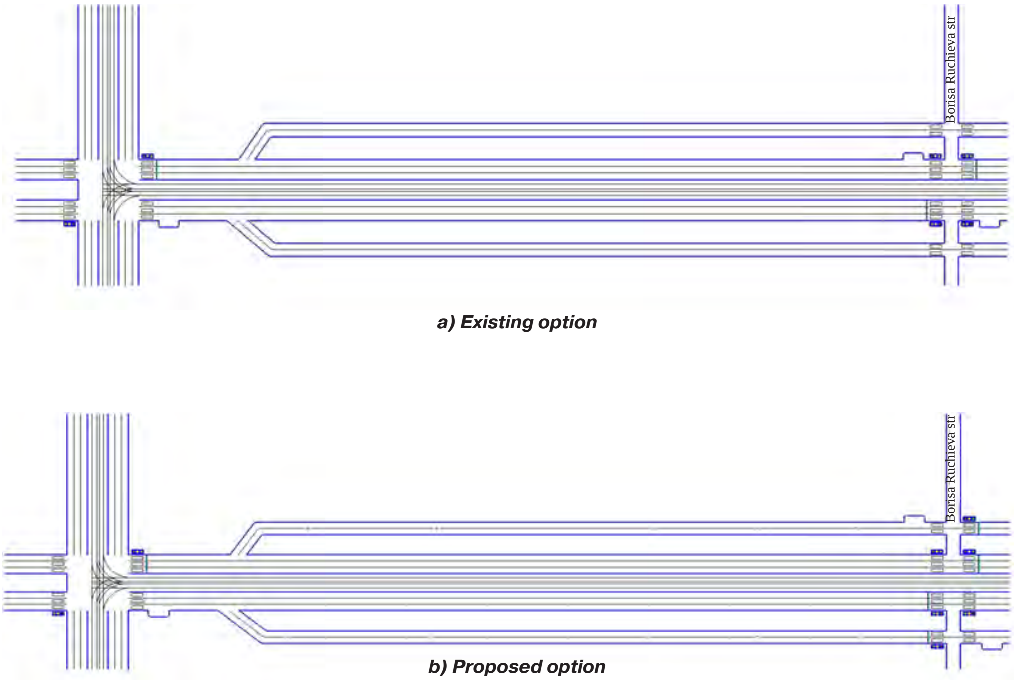


a) Existing option



b) Proposed option

Pic. 6. Schemes of organization of road traffic in Magnitogorsk along Karl Marx Avenue from Zavenyagina street to Borisa Ruchieva street.



Pic. 7. Schemes of organization of road traffic in Magnitogorsk along Karl Marx Avenue from Borisa Ruchieva street to Truda street.

Table 3

Results of technical-economic analysis of options of organization of operation of the bus route No. 33

Indicator, units	Existing option	Proposed option
1. Number of buses on the route, units	8	6
2. Annual volume of transportation, persons	469111	469111
3. Annual operating expenses, thous. rub.	11680,9	9917,72
4. Expenses for formation of transport infrastructure, thous. rub.	–	2553,1
5. Reduced expenses, thous. rub./year	11680,9	10428,34
6. Prime cost of transportation, rub./persons	24,9	22,23
7. Annual economic effect, thous. rub.	–	1252,56

route by 2 units to sufficiently comply with the specified traffic interval and will permit to reduce the total cost of transporting one passenger by 2,7 rubles. The estimated annual economic effect from implementation of the proposed recommendations is 1,25 million rubles.

Conclusions

1. One of the ways to increase efficiency of urban passenger transportation is acceleration of flow of fixed-route vehicles through its redistribution to alternate roads, doubling the main roads in the periods of their load, which allows to increase the traffic speed. Despite detailed examination of the problem under consideration, implementation of the proposed methods to accelerate fixed-route vehicles require their tuning and refinement for individual features of planning solutions of the road network of a specific city, which often does not have undeveloped areas for road construction.

2. Effect of reduction of expenses for passenger transportation when directing buses to alternate roads in the periods of load of the road network is achieved by reduction of number of buses on the route followed by respect of preset traffic intervals as a result of increase in traffic speed. The calculation of the economic effect is based on dependences proposed in the work: which are dependence

of speed of traffic flow on intensity of movement, as well as dependence of technical speed of bus movement via the alternate road on intensity of traffic flow of fixed-route vehicles.

3. The dependences were obtained based on the results of modelling of four modes of passing through light-controlled intersections:

• first mode: movement from the green light to the green light under the presence or absence of traffic jam at the next intersection;

• second mode: movement from the red light to the red light with a traffic jam at the next intersection;

• third mode: movement from the red light to the green light under the presence or absence of traffic jam at the next intersection;

• fourth mode: movement from the green light to the red light when there is traffic jam at the next intersection.

The calculations considered different levels of traffic load of the road network, when a vehicle overcomes a congestion before the regulated intersection during one, two or three cycles of the traffic light, respectively.

4. The calculation of the economic effect from direction of fixed-route buses to alternate roads during the periods of high load of the road network was made using the example of bus route No. 33 of the city of Magnitogorsk. The calculations made it possible to establish that the redirecting during the periods of peak load of road segments in the southern part of Karl Marx Avenue to alternate roads from 15:00 to 18:00 increases the traffic speed on the bus route under consideration from 11 km/h to 18 km/h. The transit time is reduced from 15 minutes to 9 minutes. Such a measure will exclude an increase in demand for buses on the route by 2 units while ensuring the compliance with the specified traffic intervals between the buses and will allow to reduce the total cost of transporting a passenger by 2,7 rubles. The estimated annual economic effect from implementation of the proposed recommendations is equal to 1,25 million rubles.

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Photo: mos.ru, Evgeny Samarin.

THE LONGEST SEASON OF BIKE-SHARING IN MOSCOW

Bike-share users made 5 million trips, that is almost by 17 % more than in 2018.

During the seventh year of its operation, Moscow bike sharing saw the longest season, almost seven months. Opened on 20 April, bike-sharing stations closed on 17 November, this late for the first time. The season was extended due to the warm weather and the large number of requests from Muscovites.

Moscow bike-sharing system is one of the fastest growing in the world. Over the five years, the project's scale has doubled. In 2015, there were 300 stations with 2,600 bicycles. This year, 528 stations with some 5,500 bicycles offered in different Moscow districts were available to citizens.

In 2019, the map of the most popular bike-sharing districts highlights Khamovniki, Tverskoi, Presnensky, Ostankinsky, Maryino, Ochakovo-Matveevskoye, Nagatinsky Zaton and Lefortovo.

Two bike-share users have become heroes of the last season. One of them travelled more than 10,000 km around Moscow — a route covering the distance from the equator to the South Pole. Another user rented a bike 3,300 times. Last year, a Muscovite rented a bike 2,500 times.

Moscow bike-sharing is leading in terms of demand among residents: on average, a bike is used for 6,4 trips per day, which is twice more than in London, one of the leading cities in bike-sharing, with 2,6 daily trips per bike.

The average ride time is 27 min.

E-bikes are growing popular, too, with 125,000 rides made this year. To date, there are 429 e-bikes to share in Moscow. Next year, this number will almost double, with 729 e-bikes available.

Next year, some 100 stations are expected to open, with 1,000 bicycles more. So, bike sharing will cover the entire city. Experts will assess the proposals of the best sites to open new stations, and analyse where the bike sharing was the most in-demand as of the end of 2019.

A total of 1,600,000 people have registered in the system since the velobike's launch. For Muscovites, a bike is now a popular and common way to get from one spot to another.

Thanks to the bike-sharing development, Moscow cyclists have become active traffic participants. Bike festivals are regularly held in Moscow, with three events already scheduled for 2020.

Electric kick scooter sharing, opened in Moscow in 2018, is growing popular, too. This year more than half a million trips have been made. This is almost four times more than the previous year, when kick scooters were rented 140,000 times. During its operation, the service has grown popular among Muscovites, with trips in the city centre becoming a common thing. In total, about 350,000 users are registered in the operators' systems.

Compiled from the news on the official Moscow Mayor website: https://www.mos.ru/en/news/item/65374073/?utm_source=search&utm_term=serp ●