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Application of Passenger Flow Analysis Methods to Restructuring the Passenger Transport System of the Levoberezhny District of Moscow

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ABSTRACT

One of the key problems when ensuring the quality of life of residents of large cities of the world is to raise the transport services standards. Among the main aspects of solving this problem is the search for the optimal distribution of flows of personal and ground public municipal passenger transport. In this regard the planning, design, and localization of multifunctional transport interchange hubs (hereinafter – TIH) take on great significance. The experience of their arrangement has received wide acceptance in many countries of the world. In recent years Moscow has also been actively working on the design and construction of TIH; large-scale projects of transport infrastructure facilities construction are being developed. The TIH system should be capable of flexible response to changing transport needs of the population and to their realistic transformation to effectively ensure transport mobility of the population.

The objective of the study is to test the passenger flow analysis methods and their application for simulation of the organization and planning of the transport interchange hub in a large district of the city, planning of the route network of municipal passenger transport.

The route network of suburban and intercity transport of Northern Administrative District of Moscow has been reviewed. The passenger traffic within the TIHs Rechnoy vokzal and Khovrino has been analyzed.

Based on the study, the authors propose to change the route network of ground urban passenger transport. The implementation of route network changing proposals can shorten the time spent on passenger travel and transfer. It is the authors' opinion that the developed route network is more effective than the existing one and meets the design standards and requirements approved by local city regulations.

Keywords: transport, ground public municipal passenger transport, airport, passenger transportation, suburban transportation, route network, transport interchange hub.

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Introduction

Despite global research and practical changes in the field of passenger traffic there is a number of problems that need to be addressed in order to ensure a balanced and step-by-step development of transport infrastructure.

Among such problems is the improvement of transportation by ground municipal passenger transport which affects the mobility of the urban population and its needs for transportation services. Under the conditions of social and economic changes aimed at improving the quality of life of citizens the role of urban automobile passenger transport is constantly growing.

This problem is typical for many world megalopolises. Thus, according to the statistical bulletin of the Ministry of Transport of Russia (January–June 2019), the share of automobile transport in the total volume of public transport traffic is about 89 %, while the passenger turnover is 21 % [1, p. 1].

Improvement of the quality of transport services provided to the city population is in many respects due to the optimal distribution of flows of personal and ground municipal public passenger transport.

Transport interchange hub (TIH) is an important infrastructure facility of public municipal passenger transport system, which optimizes the transportation process when forming and redistributing the passenger flows between different modes of transport. Development of effective management model for different modes of passenger transport results in improving the quality of transport service by reducing the transfer time [2, p. 35].

Extensive experience in the design of planning pattern of multifunctional transport hubs has been accumulated in foreign countries. For example, in recent years, Japan has been carrying out a comprehensive modernization of its entire transport infrastructure. This facilitated the deep integration of common urban passenger transport and automobile and rail transport [3, p. 244]. When developing the large urban planning projects in Japan, special attention is given to the development of the TIH system.

Different methods are used to plan and assess the efficiency of urban transport systems. We can cite the example of the use of binary logistics models used to improve the satisfaction of the passengers of bus routes in Montreal [4, p. 242]. The researchers form Calabria University (Italy) applied a specific method to evaluate transit service quality through the model of structural equations [5, p. 107]. Numerous examples of the same kind exist in many countries.

At present the transport and transport infrastructure of Moscow is the latest stage of formation and development. Its implementation should ensure that the urban systems of given modes of transport flexibly response to changing transport needs of the population and their consecutive transformation to effectively ensure transport mobility of the population.

In recent years the city of Moscow has also been actively working on the design and construction of TIH; large-scale projects of transport infrastructure facilities are being developed.

The TIH system solves the following key tasks:

- Reduction of total travel time of passengers, also due to transfer time minimization;
- Road and street network load reduction;
- Reduction of federal highway loading at the entrances to Moscow.

The proper organization and planning of the transport hub operation ensure the coordinated interaction of different modes of transport as well as the passenger comfort [6, pp. 11–13].

However, when organizing the TIHs, it is necessary to solve some problems related to their rational design and placement in urban environment. First of all it should be based on modelling the existing and future passenger flows. A lot of research studies are dedicated to this subject and planning of urban passenger routes as a whole, and offer various solutions.

To solve intra-hub problems while organizing and coordinating the operations of different modes of transport within the TIH the staff of Mosgortrans [federal unitary enterprise Moscow transport] suggested authentic methodological approach to survey on origination and distribution of passenger flows in TIH [7, p. 102].

Large-scale research was conducted in Queensland University of Technology (Australia)

Pic. 1. Khovrino TIH: Pribrezhny pr., metro station Khovrino, Oktyabrskaya railway, Housing complexes Businovo and Zapadnoye Degunino, Dybenko st.

on the impact of urban environment on the passenger travelling through data meta-analysis [8, p. 526].

The team of authors of Tongji University (Shanghai, China) and Hong Kong Kowloon University conducted the large research focused on time spent by passengers en route, and on respect of the schedules. The approach was based on Travel time reliability (TTR). The multiplicity of indices was studied with the help of assessment methods and unimodal models of probability distribution [9, p. 230].

Another example can refer to the research of a team of European scientists that focused on calculating the dimensions of a bus reserve fleet in relation to the necessity to respect its timetable and ensure its regular maintenance [10, p. 171].

The *objective* of the study is to test the passenger flow analysis methods and their application for simulation of the organization and planning of the transport interchange hub in a large district of the city, as well as for planning of the route network of municipal passenger transport.

The authors use statistical *methods*, mathematical modelling, and specific methods of analysis of urban transport systems.

The studied case was associated with Levoberezhny district of Moscow. The choice was determined by its additional features that comprise presence of terminus stations, and of the routes of urban ground transport towards international Sheremetyevo airport.

The relevance of the link «city–airport» resulted in the interest shown to that topic by several researchers, e.g. by a group of authors from Qatar University and from Sultan Qaboos University (Sudan). See the expected high demand for transportation during World Cup 2022 the researchers analysed and modelled current and predictive availability of urban public transport in the airport of Doha and selected of the rational itinerary of urban routes [11, p. 35].

The authors of the present study also suggest to develop the route of urban ground passenger transport towards Sheremetyevo international airport to optimize and improve transit services provided to Moscow residents.

Results.

Analysis and review of route network of Levoberezhny district of Northern Administrative District of Moscow

In Moscow the TIHs have been greatly developed over the last years. The dedicated order of the Government of Moscow of December 23, 2015 No. 413-PP on the development of transport hubs in the city of Moscow was signed on December 23, 2015. Transport interchange hubs are open within

Table 1

Existing route network within Khovrino TIH [16–19]

No.	Route No.	Carrier / Operator	Terminal points	Time interval (frequency)
1	65	Mosgortrans	Levoberezhnaya st. – metro station Vodny Stadion	9 min
2	138	Transavtoliz	metro station Rechnoy Vokzal–metro station Rechnoy Vokzal	22 min
3	188	Transavtoliz	metro station Rechnoy Vokzal–metro station Rechnoy Vokzal	11 min
4	200	Mosgortrans	metro station Rechnoy Vokzal–Lobnenskaya st.	12 min
5	270	Mosgortrans	metro station Rechnoy Vokzal–station Khovrino	7 min
6	283	Mosgortrans	metro station Rechnoy Vokzal–metro station Rechnoy Vokzal	12 min
7	344	Mostransavto	metro station Khovrino–railway platform Levoberezhnaya	15 min
8	368	Mostransavto	metro station Khovrino–railway platform Dolgoprudnaya	5 min
9	400E	Mosgortrans	metro station Khovrino–Severnaya	7 min
10	559	Taxicab fleet No. 20	metro station Rechnoy Vokzal–Cherepovetskaya st.	18 min
11	673	Transavtoliz	metro station Rechnoy Vokzal–Businovo	10 min
12	739	Transavtoliz	metro station Rechnoy Vokzal–metro station Rechnoy Vokzal	22 min
13	745	Transavtoliz	metro station Rechnoy Vokzal–metro station Rechnoy Vokzal	11 min
14	958	Mosgortrans	metro station Rechnoy Vokzal–Yurma town	28 min

Pic. 2. Khovrino TIH.

the Moscow Central Circle (MCC) and at other locations.

For testing proposed approaches, the Levoberezhny [*if literally translated, Left Bank*] District of Northern Administrative District of Moscow was chosen as a subject of research [12, p. 4], since it's the location of one of the recent projects of development transport interchange hubs, namely of Khovrino TIH (Pic. 1) which is located near the similarly named metro station of Zamoskvoretskaya line in the Northern Administrative District of Moscow. The TIH (scheduled start-up is about in 2022) [13] will integrate the passenger flows of metro, railway, and the routes of ground public municipal passenger transport. TIH has a potential to considerably improve the traffic situation in the north of the city [14, p. 40].

So far, the analysis of Khovrino TIH operation, conducted by MADI students during educational internship, shows that the passenger flow rates are as follow:

• metro station Khovrino: 17,4 thous. persons during rush hour (expected);

Table 2

Routes of ground municipal passenger transport and their characteristics per turnover run before optimization

No.	Route No.	Starting stopping point	Terminal stopping point	Route length, km	Travel time, min
1.	342	Pavlova st.	metro station Rechnoy Vokzal	21	81
2.	343	Novogorsk-Stadion	metro station Rechnoy Vokzal	31	120
3.	344	Railway platform Levoberezhnaya	metro station Rechnoy Vokzal	22	85
4.	345	Khimki station	metro station Rechnoy Vokzal	19	73
5.	368	Railway platform Dolgoprudnaya	metro station Rechnoy Vokzal	31	120
6.	370	Housing complex Welton park	metro station Rechnoy Vokzal	42	163
7.	443	Druzhby st.	metro station Rechnoy Vokzal	23	89
8.	482	Glass factory Elvaks	metro station Rechnoy Vokzal	52	201
9.	350	Mendeleyevo (Towers)	metro station Vodny Stadion	66	180
10.	437	Klin bus station	metro station Vodny Stadion	154	300
11.	440	Solnechnogorsk bus station	metro station Vodny Stadion	105	213

• bus routes: 9,3 thous. Persons during rush hour (existing); 10,2 thous. Persons during rush hour (expected).

The commissioning of new transport infrastructure facilities, including Khovrino TIH, involves a solid piece of work to modernize and restructure the existing route network located in the zone of influence of new transport infrastructure facilities.

14 bus routes actually run through the Khovrino TIH (Table 1) [16–19].

Metro station Rechnoy Vokzal had been terminal for 53 years until opening of Khovrino station in December, 2017. However the zone train turn-over [when Rechnoy Vokzal station becomes terminus] in rush hour and on weekends is also possible at the present time.

Rechnoy Vokzal station is one of the busiest stations of the Moscow metro. Owning to the large-scale development of the Levoberezhny district and the adjacent satellite towns, the load on the station has increased several times. In March 2002 the passenger flows were as follows:

• incoming – 111,9 thous. people,

• outgoing – 148,3 thous. people [20].

Once the Khovrino station has been opened, the daily passenger flow at the Rechnoy Vokzal station on weekdays decreased by about a third compared to 2017 and amounted to 63 thousand people per day. The opening of Belomorskaya station will help to further decrease the passenger flow [20].

The bus stations for thirty-two bus routes are currently located near the metro station thus complicating transport situation in the district (Pic. 2).

Role of Khovrino TIH in the transport service of Sheremetyevo airport and development of new routes

The Khovrino TIH is located 12 kilometers from Sheremetyevo Airport named after A. S. Pushkin (SVO), and Dybenko st., where the TIH is located, is adjacent to M-11 highway going to the airport.

Airport accessibility by transport should be improved due to the ongoing reconstruction of the airport and bringing the new terminals into service followed by the increase in the passenger flow.

At present only Aeroexpress trains form the direct non-stop route to Sheremetyevo, and that complicates the airport accessibility by transport and deteriorates the passenger service.

The following solutions can be considered as proposals for optimizing and restructuring the existing route network:

1. Develop the new express route Sheremetyevo Airport–Khovrino TIH;

2. Redistribute the existing bus routes from Rechnoy Vokzal TIH to Khovrino TIH.

It is proposed to develop the new express route to Sheremetyevo Airport with the following characteristics [14]:

• departure point is metro station Khovrino;

• terminal point is Sheremetyevo Airport, terminal D;

Table 3

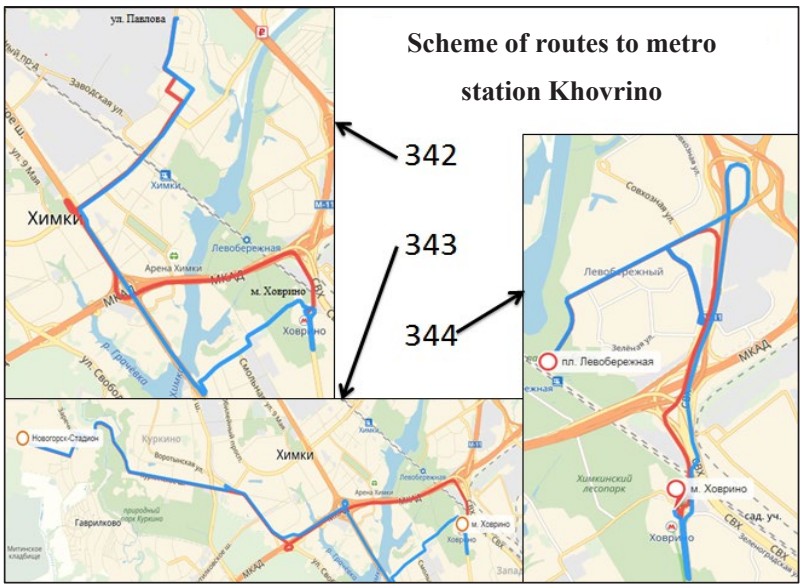
Routes of ground municipal passenger transport and their characteristics per turnover run after optimization

No.	Route No.	Starting stopping point	Terminal stopping point	Route length, km	Travel time, min
1.	342	Pavlova st.	metro station Khovrino	17	63
2.	343	Novogorsk-Stadion	metro station Khovrino	24	89
3.	344	Railway platform Levoberezhnaya	metro station Khovrino	12	44
4.	345	Khimki station	metro station Khovrino	13	48
5.	368	Railway platform Dolgoprudnaya	metro station Khovrino	24	90
6.	370	Housing complex Welton park	metro station Khovrino	40	150
7.	443	Druzhby st.	metro station Khovrino	21	78
8.	482	Glass factory Elvaks	metro station Khovrino	50	187
9.	350	Mendeleyevo (Towers)	metro station Khovrino	61	165
10.	437	Klin bus station	metro station Khovrino	148	275
11.	440	Solnechnogorsk bus station	metro station Khovrino	100	200

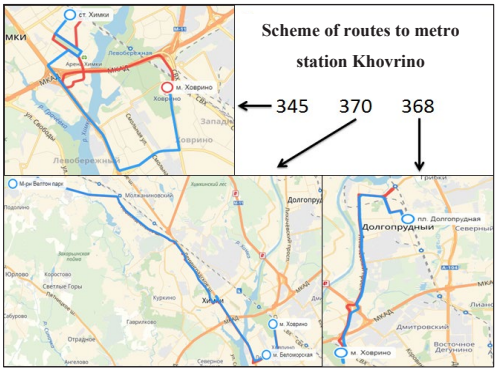
Table 4

Comparison of indices. Optimization results

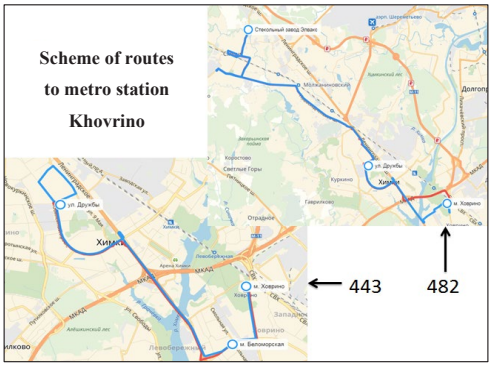
No.	Route No.	Turnaround run distance before optimization, km	Turnaround run distance after optimization, km	Route distance change, km
1.	342	21	17	4
2.	343	31	24	7
3.	344	22	12	10
4.	345	19	13	6
5.	368	31	24	7
6.	370	42	40	2
7.	443	23	21	2
8.	482	52	50	2
9.	350	66	61	5
10.	437	154	148	6
11.	440	105	100	5
TOTAL		566	510	56



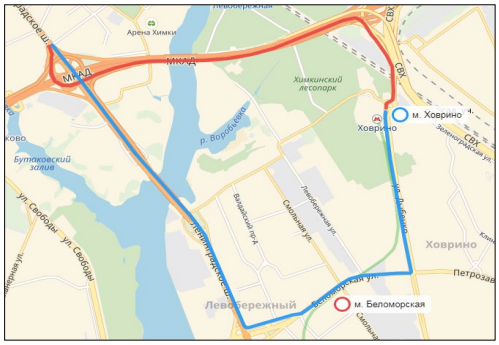
Pic. 3. Routes No. 342, 343, 344.



Pic. 4. Routes No. 345, 370, 368.



Pic. 5. Routes No. 443, 482.



Pic. 6. Layout of access road to Khovrino TIH of intercity routes No. 350, 437, 440.

Pic. 7. Khovrino Transport Interchange Hub. Severnye Vorota bus station.

• route length is 13 km;

• travelling time is equal to 30 minutes;

• time interval (frequency) is ~25 minutes;

• the fleet comprises LiAZ 6213.71 buses.

Proposals for optimizing the suburban and intercity transport network due to bringing the Khovrino TIH into service

For optimizing the work of suburban and intercity transport network the existing routes of suburban and intercity transport were analyzed and their characteristics were defined (Table 2).

Transport service of passengers from the Khimki urban district, Dolgoprudny, Klin, Solnechnogorsk towns and the worker's settlement [small town] Mendeleevo is provided at the indicated routes of the Mostransavto motor transport enterprise. 1–8 routes are suburban and 9–11 routes are the intercity ones. The routes are used for passenger transportation to Moscow therefore it is reasonable to use the nearest metro station for this purpose.

To optimize the expenditures and shorten travel time, it is recommended to re-locate the terminal stopping point of the routes of the Mostransavto motor transport enterprise.

For assessment of effectiveness of the new suburban and intercity network, the length and travel time of the suburban and intercity routes were analyzed (Tables 3, 4).

Pics. 3–6 show the routes after optimization and shift of the terminal bus stations to the metro station Khovrino (Khovrino TIH)*.

As for routes No. 350, 437, 440, the layout of changed access to metro station Khovrino is given (Pic. 6). The rest of the route remains unchanged. It will help to keep the current passenger flow and even increase it due to shortened travel time.

As a result of optimization, we got the total distance reduction by 56 kilometers per run on 11 routes. Considering the average time interval of 25 minutes for these routes and the average working time of 18 hours, the average number of runs per day will be equal to 45. Then, compared to the current route scheme, buses will travel 2520 kilo-

* The forward direction routes are red-colored and backward direction routes are blue-colored.

meters less according to the proposed route schemes.

Conclusions.

The results of the analysis of passenger flows of transport system of Khovrino (Pic. 7) and Rechnoy Vokzal transport interchange hubs showed that the transport system of Rechnoy Vokzal TIH needs to be revised. It is found that Khovrino TIH has the passenger flow intensity margin.

A new suburban and intercity transport network consisting of 11 routes was developed in order to improve the quality of passenger transportation. The comparative assessment showed that the new network has some advantages compared to the existing one. The proposals to change the route network will result in reduction of time of passenger travel and transfer. The developed route network is more efficient than the existing one and meets the design standards and requirements established by the Decree of the Government of Moscow dated December 23, 2015 No. 945-PP on approval of the regional standards for urban planning of the city of Moscow in the field of transport, roads of regional or intermunicipal significance.

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