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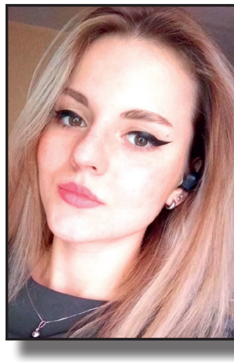
Issues of Designing and Restructuring the Route Networks of Public Passenger Urban Ground Transport





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ABSTRACT

The urban passenger public transport as an important element of social infrastructure of megalopolises directly influences the quality of life of city residents, development of town-planning, social and economic potential. Efficiency of urban transport directly depends on the right choice and well-sought designing of its routes.

The objective of the research was to develop based on the overview of existing methods for designing route networks of urban public passenger transport an updated technique allowing to restructure existing routes.

The analysis of route network design methods permitted to reveal their advantages and disadvantages. An improved methodology for designing route networks is proposed, aimed at solving the problems of restructuring existing route networks and at practical implementation of the results considering existing constraints.

The technique to design route networks of city districts and of small towns is based on the model of road and street network, shown as a detailed graph with subsequent consideration of the arrays of connections of all the vertices of the graph with several points of gravity. QGIS geoinformatics software used to build the graph allows to analyze, visualize, and facilitate the operations with the detailed graph of the transport network of a city district.

Identifying of rational itineraries between points of departure and of gravity is executed by purposed selection of options by criterion of minimum travel time spending. Shaping out of routes is based on principles of integration of the most possible number of points (vertices of the graph) into the route.

The application of an improved technique will allow to consider the changing demand of the population for transport services, make adjustments to the existing route network, thereby satisfying the population's need for transportation and increasing the efficiency of urban transport networks and motor transport enterprises.

Keywords: *passenger transportation, urban passenger transport, route network, restructuring.*

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Background. Passenger urban ground transport (PT) is the most important element of social infrastructure, affecting the quality of life of the population, the efficiency of the city's economy, the possibility of maximizing the use of its urban development and socio-economic potential [1–5]. An analysis of studies in the field of passenger road transportation, including the works of the department of road transportation of MADI [1; 2; 4; 5], allows to conclude that PT should provide maximum transport accessibility for residents throughout the city, taking into account its promising development. And this, in turn, determines the need for designing new and restructuring the existing PT route networks [6; 7].

The need to restructure the route network is due to the following factors:

1. Unevenness of passenger flows on the lines of the route network;
2. Growth of the territory of urban areas;
3. Organization of new points of gravity (construction of off-street transport stations, opening of new shopping and entertainment centers, etc.);
4. Changes in urban infrastructure (construction of new roads, bridges, etc.).

Objective. The objective of the authors is to consider issues of designing and restructuring the route networks of public passenger urban ground transport.

Methods. The authors use general scientific and engineering methods.

Results.

Analysis of methods for designing and restructuring route networks of urban ground passenger transport

The international experience in designing route networks is diverse and concerns various aspects: planning multi-modal PT systems of individual cities, bus and intra-city rail routes, accessibility aspects, impact of the traveling of employed residents to and from their work place on development of the urban transport network, advantages and disadvantages of polycentric schemes, and many others issues.

Thus, the analysis of foreign studies in the field under consideration shows the need for:

1) integration of urban passenger transport systems: ensuring interaction of various modes of transport, elements of route networks and infrastructure, urban planning, environmental, and social policy [8–10].

2) an integrated approach to designing and operation of transport systems, which consists in ensuring compatibility and coordination of systems of various modes of transport, as well as technical, technological, organizational, economic, environmental, legal, information subsystems [11–13].

The studies noted the impact of estimates of demand for transport services and of predictions on the distribution of departure and arrival points of the travel on operation parameters of transport systems and route networks. The role of questioning various social groups in determining the demand for transport services is revealed. The factors affecting the use of public passenger transport have been also identified [14].

Numerous issues were studied comprising problems and effects of restructuring of existing route networks in terms of canceling, expanding, changing routes, designing infrastructure, adjusting the location of stopping points, eliminating unreasonable duplication of routes, designing joint tram and bus networks, creating multimodal transport systems, introducing new modes of transport and assessing their impact on transport system operation, a study of the dependence of demand for transport services on the number of interchanges and time for interchanges. Modelling of the transport system using Visum macro monitoring tool is proposed [10].

When designing networks, it is recommended that factors such as reliability, stability, power, constraints imposed regarding network capacity and load, and economic restrictions be considered. Various methods and models of network design are considered [15].

The combinatorial nature of network design problems is noted, which involves consideration of many options. The stages of designing route networks have been distinguished: demand estimation, deployment of stopping points, compilation of a correspondence matrix, selection of effective routes. The principle of routing with time limits for travel passing by a priori given stops was considered [16].

A method is proposed for modelling discrete events when solving the problem of restructuring route networks, which allows considering the dynamic nature of bus routes and making changes to the existing route network [17].

Thus, international experience shows that the solution to the problems of designing and optimizing route networks can be carried out using a complex of analytical, mathematical, probability and theoretical methods.

This topic has attracted the attention of Russian researchers. There are several works, the main provisions of which can be used in solving problems in the field of designing and restructuring route systems of urban passenger transport. This includes the works of B. L. Geronimus and D. D. Dzhumaev [18], G. A. Varelopulo [19], E. A. Safronov [20], M. V. Khrushchev [21]. However, the methods proposed in these studies do not fully reflect current realities, do not take into account all the necessary limitations, and, therefore, make it possible to obtain «rough» solutions only that are difficult to be implemented.

For the first time, the complex task of designing a route network of urban passenger transport was solved in the 60s by NIIAT [Research Institute of Motor Transport] specialists [18]. The method of combinatorial analysis was basic, as it provided for the principle of directional selection of options for finding the optimal solution. Various optimization criteria have been proposed, including the total time spent by all network passengers on travel, including time spent on foot crossings [21], waiting and traveling in transport, interchanges between routes. The main disadvantages of the methodology are lack of restrictions, high time losses and laboriousness of calculations due to the need to manually calculate many options.

The method proposed in the 90s of the last century by the chief engineer of the Traffic Service of the Passenger Transport Administration of Moscow City Executive Committee G. A. Varelopulo [19] is that for a transport network, presented in the form of a graph: a set of vertices (centers of micro districts) and edges (driveways, tertiary streets) by which passenger traffic can be organized, time-efficient travel paths (transport links) were determined. Then, based on the obtained array of connections, the routes were constructed taking into account inclusion of the maximum possible number of vertices in each route. At the same time, several restrictions were established to reduce the number of options considered. For calculations, a special computer program was developed. The disadvantages of this method are the difficulty of practical implementation due to the large number of routes and the insufficient number of restrictions. For example, the capacity limits of the road network and transport hubs are not taken into account. In addition, this technique involves design of a route network from scratch, without providing for the restructuring of existing route networks.

M. V. Khrushchev [21] proposed separation of routing methods into two groups depending on the level of tasks to be solved, namely general routing methods (the main of which is search for an optimal bus route scheme) and local routing methods (correction of individual routes). The author was convinced that acceptable results can only be achieved by combining approaches at different stages of development of a rational route scheme [1].

The advantages of this approach comprise use of various methods for solving routing problems, depending on the goal; high accuracy of the results and ability to optimize existing routes due to orientation on data on the distribution of departure and arrival points of travel; ability to choose the best route scheme based on quality criteria for passenger transportation; possibility to check feasibility of functioning of the developed route scheme.

The disadvantages include lack of significant restrictions to reduce the number of compared options for route networks [1]; application of these methods is only possible in the presence of stable ties between the city districts.

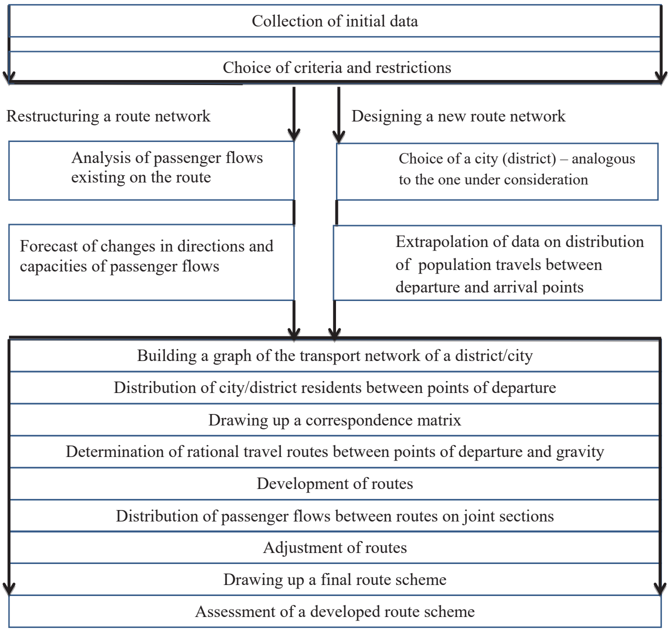
Improving the methods of designing and restructuring urban route networks

Designing and restructuring of route networks should be carried out in strict accordance with the provisions of the legislative and regulatory framework, which must be taken into account when choosing criteria and limitations within the problem, as well as when analyzing a developed or an optimized version of the route network. Within the territory of Moscow region, it is necessary to be guided by the following documents and acts:

1. SNiP [hereinafter SNiP means constructions norms and rules], Part II Standards for building design (1954) is advisory in nature, because it has lost legal force;

2. Urban Planning Code of the Russian Federation dated December 29, 2004 No. 190-FZ [Federal Law] (as amended and supplemented on August 2, 2019, entered into force on August 13, 2019);

3. SNiP 11-60-75 on Planning and development of cities, towns and rural settlements;



Pic. 1. Stages of designing and restructuring the route networks of urban areas and small towns.

4. SNiP 2.07.01-89 on Urban planning. Planning and development of urban and rural settlements;

5. SP [construction rules] 42.13330.2016 on Urban planning: Planning and development of urban and rural settlements (updated edition of SNiP 2.07.01-89);

6. Norms and rules for design of town-planning and development of the city of Moscow MGSN1.01-99;

7. Decree of the Government of Moscow of December 23, 2015 No. 945-PP on approval of regional standards for urban planning of the city of Moscow in the field of transport, roads of regional or intermunicipal significance.

The analysis of existing methods for designing route networks determines the need for:

• differentiation of methods depending on the size of the object of study and the goal;

• improvement of methods to ensure the possibility of practical implementation of the results.

The need to improve the design methods of route networks is caused by the following factors:

1) when choosing a restructuring methodology, it is necessary to take into account the size of the territory of cities or regions, the presence of stable passenger flows towards gravity points;

2) to solve the problems of restructuring route networks, it is necessary to change the way how the distribution of travels between departure and arrival points is made;

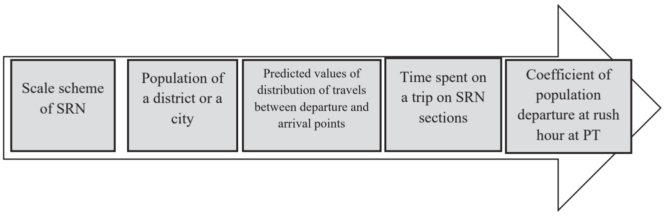
3) existing methods for designing route networks allow to get a theoretical model that is difficult to be put into practice;

4) for the possibility of practical implementation of the results of the restructuring, introduction of additional restrictions is necessary.

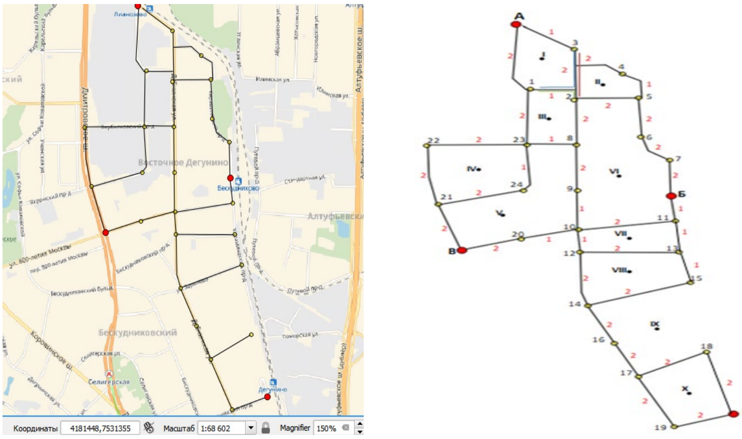
In the case of designing route networks of medium and large cities, it is advisable to use an enlarged method based on compilation of a matrix of inter-district travel correspondence and choice of routes considering given criteria and restrictions. Moreover, each district of the city will be represented by a single destination address, which is the conditional «center of gravity» of this area. This will significantly reduce the number of options considered and will enable further adjustments to the developed routes.

When solving the problems of restructuring route networks, it is necessary to change the way distribution of departure and arrival points is received. In this case, the correspondence forecast will be carried out not according to the data of the analogous area or based on the calculation of transport mobility of the population, as is possible when designing new networks, but according to the results of the passenger flow survey at the existing route network. When forecasting distribution of departure and arrival points, it is also necessary to take into account the throughput and loading of transportation hubs, the presence of new points of gravity (places of employment, cultural and public

Pic. 2. Initial data in design and restructuring route networks.



Pic. 3. An example of a detailed graph of the transport network of a city district.



facilities that are massively visited, stations of off-street transport, etc.).

To obtain possibility of practical implementation of the design option the route network requires introduction of additional restrictions to reduce the number of routes received at the design stage and taking into account the permissible transit capacity of the route, the load on the street-road network (SRN), the required level of quality of passenger service, the degree of unevenness of passenger flows and the efficient use of rolling stock [19; 22].

However, existing methods for designing and restructuring route networks do not fully consider the necessary limitations, which results in difficulties while implementing the results.

When designing route networks of city districts and small cities, the model of a street-road network presented in the form of a detailed graph with subsequent consideration of the arrays of connections of all the vertices of the graph with several points of gravity can be taken as a basis (Pic. 3).

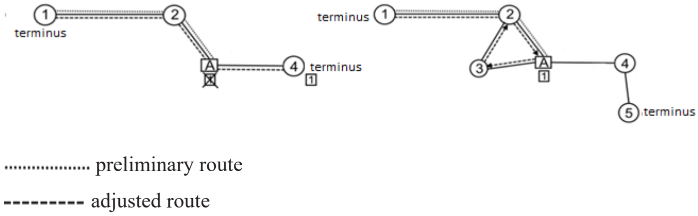
To build a graph, it is possible to use QGIS geographic information system which is a convenient tool that allows to load a city map, select a scale, quickly and clearly build, edit vertices and segments (sections of the street-road network) on top of a loaded map, measure the length of roads, streets, graphs constructed in scale and more. Due to this, it is possible to analyze, visualize and simplify work with a detailed graph of the transport network of the city district.

The identification of rational travel routes between points of departure and gravity is carried out by the method of directional selection of options according to the criterion of minimum time spent on movement. The identification of routes is carried out according to the principle of integration into the route of the greatest possible number of points (vertices of the graph) [19].

Adjustment of routes developed at the initial stage is based on the following conditions:

1. It is not permitted to organize routes at certain sections of street road network. In accordance with the standards in force in Moscow [23; 24], the width of the lane for ground passenger transport should be equal to 3,75 m. The width of local tertiary streets when organizing movement of mass passenger transport should be taken for one-way traffic as 10,5 m; for two-way traffic as 11,25 m.

2. It is not allowed to organize destination points of routes when technical feasibility of construction of a terminus is missing. A possible solution is to extend the track of the route to



Pic. 4. Options for adjusting the route in the absence of the possibility of organizing the terminus.

the point with the terminus, or to organize turnover of vehicles through circular traffic while maintaining the main direction of the main passenger outgoing flow (Pic. 4).

When extending a route, a situation arises when the same connection is served by multiple routes with different travel times. For distribution of passenger flows between these routes, the condition can be admitted that the number of passengers assigned to the route is inversely proportional to travel time:

$$K_t = \frac{\sum t_m}{t_m};\; Ps_m = P_s \bullet \frac{K_t}{\sum K_t},$$

where K_t is distribution coefficient of passengers over time,

t_m is travel time of passengers of common link using the *m*-th route, min.

3. Establishment of maximum permissible values of maximum passenger flow on sections of the route. They are determined on the basis of the maximum and minimum permissible frequency (intervals) of movement, limited by SRN throughput and the necessary level of passenger service quality, as well as the maximum and minimum values of the nominal capacity of vehicles available for the transport company serving the route network:

$$Q_{jmax}^{min} = \frac{q_{nmin} \bullet 60}{I_{max}};\; Q_{jmax}^{max} = \frac{q_{nmax} \bullet 60}{I_{min}},$$

where q_{nmin} and q_{nmax} are respectively minimum and maximum nominal capacity of vehicles, people;

I_{max}, I_{min} are maximum and minimum allowable values of the interval of movement of vehicles during «peak» hours, min.

If the estimated value of the maximum passenger flow on the route exceeds the permissible range, the following solutions are possible:

1) Organization of semi-express traffic on the route (if there are duplicate routes in this direction, having an extra capacity) (Pic. 5);

2) Organization of an additional shortened route on the most loaded section (Pic. 5).

If the estimated value of the maximum passenger flow on the route is below the permissible range, the following solutions are possible:

1) Exclusion of a route with distribution of passengers between the nearest neighboring points of departure (vertices of PT). In this case, it is necessary to consider the current regional standards for the length of pedestrian approaches.

For the city of Moscow, distances from ground transport stopping points should not exceed 400 m to places of residence or places of employment; 150 m to shopping centers, department stores, hotels, clinics; 400 m to other facilities [23; 24].

2) Exclusion of a route and organization of transport link with an interchange (in the presence of alternative routes having an extra capacity).

4. The combination of routes obtained at the initial stages.

It is carried out in the following cases:

1) a route is a continuation of the other route;

2) routes overlap to great extent;

3) a route is an integral part of another one (except for cases of organizing an additional shortened route).

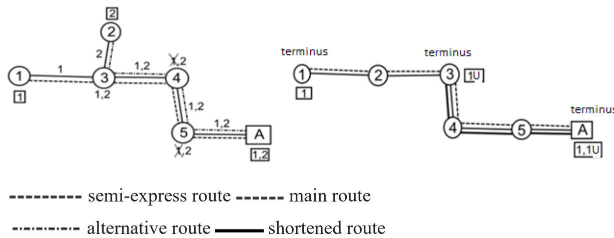
Conclusion. Thus, the proposed improved methodology for designing and restructuring the route networks of small cities and city districts provides for:

1. Differentiation of methods for obtaining forecast values of correspondence between departure and arrival points for design and restructuring tasks.

2. Consideration of requirements for SRN parameters when planning routes.

3. Consideration of various options for turnover of vehicles at final points of routes.

4. Establishing restrictions on the maximum passenger flow taking into account the capacity of the transport system and quality of passenger service.



Pic. 5. Options for adjusting the route by organising semi-express service and an additional shortened route.

5. Consideration of time factor while distributing passengers between alternative routes.

6. Measures to reduce the estimated values of passenger flows.

7. The possibility to reduce the number of routes under consideration by combining them and excluding them taking into account compliance with standards for transport accessibility.

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