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# Development of an Approach to Improving the Passenger Transport Routing Scheme in a Large City

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## ABSTRACT

*Despite high importance of mass passenger transport for ensuring mobility of urban population, the current period is characterized by a pronounced shift in priorities in implementation of measures for development of the transport system of a large city towards private transport. Along with impossibility of maintaining high rates of construction and reconstruction of the main street and road network, such a position regarding urban planning results in significant overload of almost the entire transport infrastructure of a large city. In the opinion of most experts, key measures aimed at stabilizing the transport situation in cities should comprise implementation of a policy of active development of the mass passenger transportation system. Among the issues of organizing passenger transport operation, the most interesting is the procedure for tracing routes followed by subsequent development of a rational routing scheme, since in many respects the urban passenger travel time will depend on the results there-of. Improvement of the passenger transport routing scheme, considered in relationship with development of the city's main street and road network, will allow achieving the required level of convenience by increasing traffic flow speed.*

*After reviewing domestic and foreign works devoted to the study of urban transportation systems, it was found that the known methods of development of passenger transport routing schemes do not fully consider the interaction of traffic flows with urban main roads. Often, experts pay insufficient attention to optimization criteria that allow a comprehensive analysis of rationality of routing schemes options. Analysis of the requirements for bus routing, the choice of priority directions for their development and convenience of movement made it possible to generalize the principles of designing routing schemes and to assign criteria for their optimization. It has been established that speed is the most significant criterion for optimizing transportation systems, considering the peculiarities of the organization of traffic flows on the road network of a large city and its transport and operational conditions. Based on the routing experience accumulated over almost a century, an approach has been developed to reasonable assignment of measures for reorganizing the routing scheme, which allows us to consider the factors that determine the technical condition of the road network and the characteristics of traffic flows. Its general idea is to connect separate links of the transport network and to sequentially develop a set of competing route options, one of which will later be included in the rational routing scheme.*

*Keywords:* *urban passenger transport, route, routing scheme, street and road network, optimality criteria, travel time.*

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**For the original Russian text of the article please see p. 174.**

**Background.** The vital activity of a modern large city is supported by its infrastructure, in which the street and road network, as well as passenger transport operating on that network, occupy the central positions. It is necessary to highlight the high social importance of urban passenger transport, which manifests itself in ensuring freedom of movement of city residents and in reducing travel time.

To date, the degree of development of urban transport infrastructure does not allow to fully meet the transport needs of the population. First, this is due to a decrease in the pace of construction, reconstruction, and overhaul of transport infrastructure, e.g., roads. Transport problems are most acutely expressed in large cities, the planning scheme of which have been taking shape for a long period of time under the influence of historical factors. Under such conditions, insufficient development of road transport infrastructure leads to the fact that passenger travel time significantly exceeds the maximum permissible values [1; 2]. This contradicts the basic rule formulated earlier by the French architect Le Corbusier, according to whom the rate of modernization of transport infrastructure should not lag behind the rate of development of the city as a whole [3]. In turn, construction of new main streets and roads will require freeing of urban areas, which means that it will necessarily be accompanied by demolition of existing buildings. A more humane solution to the indicated problem is the rational use of underground and aboveground space, however, this will also require colossal investment. At present, one can observe the opposite, extremely negative phenomena, such as manifestation of activity in development of free urban areas and, above all, promising peripheral zones for mass housing construction and building of large shopping and entertainment complexes, which leads not only to significant congestion of transport roads, but to overload of the entire engineering infrastructure of a large city.

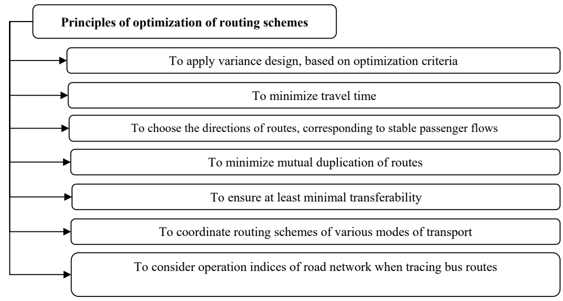
An increase in economic activity of the population, accompanied by an increase in transport mobility of citizens, leads to the fact that the daily use of a car becomes more attractive. At the same time, a passenger car is characterized by a low carrying capacity, while occupying a significant area of the carriageway. This testifies to ineffectiveness of using this type of passenger transport for performance of job travels that are stable and massive in certain periods of time. At the same time, it is obvious that all movements of townspeople cannot be realized exclusively by public transport. It should be noted that cars play an equally important role in organization of the transportation process, because they can provide a significant part of urban travelling with cultural, domestic, and mixed purposes [4].

A significant increase in motorization, characteristic of cities in Western Europe and the United States in the post-war period, has caused the emergence of serious crisis phenomena, accompanied by traffic congestion, a decrease in car speeds and, finally, an increase in road traffic accidents. Even then, it became obvious to specialists that urban roads laid before mass emergence of cars did not correspond to the parameters of traffic. Later, many experts recognized the erroneousness of the previously chosen course and the need to implement a policy that presupposes development of a mass passenger transport system [5–10]. At the same time, the researchers note [5; 7; 9; 10] that the sole increase in attractiveness of mass transport does not allow by itself achieving the desired level of decrease in intensity of urban traffic flows. Besides, the pressure of the automotive industry contributes to distraction of attention of citizens from mass passenger transport and to development of the habit of using private transport.

According to experts [11; 12], Russia lags behind some developed countries in terms of transport infrastructure development by more than 20 years, repeating the mistakes of other countries and, as a result, experiencing the same problems. Thus, the design solutions currently being developed in our country to a greater extent reflect the interests of the owners of private passenger cars, which provide no more than 40 % of the volume of passenger traffic. When modernizing the city's transport framework, attention paid to route operated types of public transport, represented by an insignificant share in the flow structure, but at the same time carrying out the bulk of passenger traffic, is clearly insufficient [1; 4; 12].

The pronounced disproportion in priorities for development of mass and private passenger transport contributes to strengthening of opposing of competing types of passenger transport to each other, and, as a result, brings the indicated problem to the highest urban planning level [13].

Many researchers [2; 3; 8; 12; 14–17] note that the choice of a rational routing scheme takes one of the most important places among the issues of organizing mass passenger transport operations. Urban passenger travel time largely depends on




***Pic. 1. Principles of optimization of routing schemes (authors' scheme).***

how well the routing scheme is developed. In this regard, the routing scheme must be considered in relationship with the city's road network.

Since the 30s of the last century, scientists from all over the world have been working on improving bus route schemes. In Russia, the works of A. P. Aleksandrov, L. A. Bronstein, A. Kh. Zilbertal, V. S. Larionov, A. A. Polyakov, D. S. Samoilov are fundamental in design of urban passenger transportation systems. The works of B. L. Geronimus, D. Dzhumaev, M. E. Antoshvili, V. M. Buneev [1], G. A. Varelopulo, I. V. Spirin [3], E. A. Safronov, M. V. Khrushchev [15], F. G. Glik [14], S. Yu. Olkhovsky [16] and V. V. Yavorsky are devoted to development of scientifically grounded methods of constructing bus routing schemes. Among the works of foreign authors, of particular interest are scientific studies devoted to the issues of modelling the public transportation network [18].

As a result of studying the experience of routing, it has been established that the existing methods for constructing optimal routing schemes require clarification of their provisions, since they do not consider technical parameters of city streets and roads. Thus, further development of an approach to reforming the routing scheme in relation with operation of the backbone network is an urgent issue.

The analysis of the requirements for operation of urban passenger transport, presented in some detail in scientific sources, made it possible to single out the main principles of optimization of traffic routing patterns (Pic. 1) [4].

The application of the principle of multivariance is due to complexity and ambiguity of the problem of routing for urban passenger transport and is dictated by the need to choose the most rational solution. Since the quantity of options can be large, it is important to use methods that reduce the number of possible options. This can be achieved by eliminating unrealistic and uncompetitive options, as well as by selecting only a certain category of them for further detailed consideration [15].

The presentation of the objective in the form of a set of performance criteria is the most important stage in the study of the urban passenger transportation system. In this case, the most effective method is the one that allows us to search for a solution according to one of the most important criteria with transfer of the rest to the category of constraints. In general, it can be written as follows [4]:

$$\begin{cases} X \to extrem \\ Y_1^{min} < Y_1 < Y_1^{max} \\ \dots \\ Y_n^{min} < Y_n < Y_n^{max} \end{cases}, \qquad (1)$$

where X is the most important criterion, determined based on expert estimates;

Y is a set of secondary criteria sufficient for a full description of the role of the object under the study.

The criteria for optimizing individual routes and routing schemes adopted in the work are presented in Table 1 [4]. According to most researchers, the main criterion may be travel time. Moreover, the norms of time spent on job travel are established by the current regulatory document [19].

Considering the multicriteria nature of the routing problem, the approach to choosing the most rational solution should be presented in the form [4]:

for a routing scheme:

$$\begin{cases} t_{av} \to min \\ l_{min} < l_r < l_{max} \\ K_n < K_n^{max} \\ K_{use} > K_{use}^{min} \\ B_{av} < B_{max} \end{cases},$$

for a separate route:

$$\begin{cases} t_{av} \to min \\ K_r^{min} < K_r < K_r^{max} \\ \delta_r^{min} < \delta_r < \delta_r^{max} \\ K_t^{min} < K_t < K_t^{max} \\ K_n^{min} < K_n < K_n^{max} \end{cases}. \qquad (2)$$

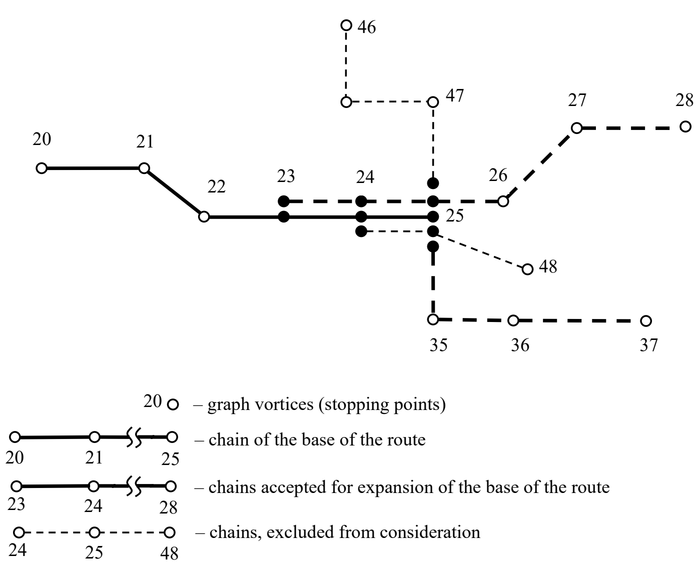
**Table 1**

**Criteria for optimization of passenger transport routing schemes**

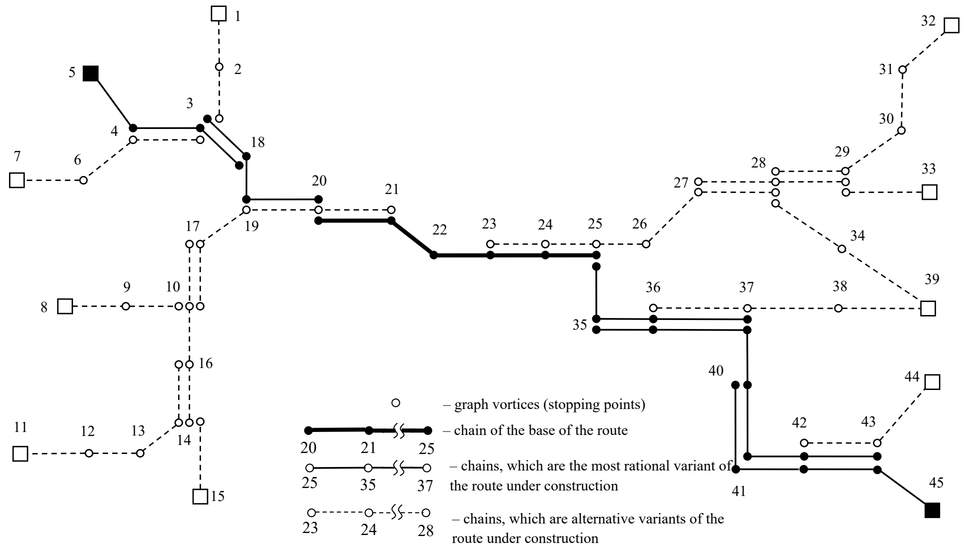
| Optimization area | Name of optimization criteria | Rational limits of variance of criteria |
|---|---|---|
| Routing schemes | Average city resident travel time $t_{av\ tot}$ | $t_{av\ tot} < 40$ min |
| | Transferability coefficient $K_t$ | $1,15 < K_t < 1,30$ |
| | Route coefficient $K_r$ | $2,0 < K_r < 3,0$ |
| | Density of the route network MC $_r$ | $1,5 < {}_r < 2,5$ |
| | Coefficient of non-straightness of trips within the route network $K_{n\ tot}$ | $K_{n\ tot} < 1,25$ |
| Bus routes | Average passenger travel time $t_{av\ MT}$ | – |
| | Length of the route $l_r$ | ordinary 15–30 km<br>circular up to 40 km |
| | Coefficient of use of provided seats [occupancy] $K_{use}$ | $K_{use} > 0,5$ |
| | Indicator of road surface condition $B_{av}$ | $B_{av} < 3,0$ |
| | Coefficient of non-straightness of trips within the route $K_n$ | $K_n < 1,25$ |

Among the known approaches to improving the current routing scheme, the method of successive approximation to the optimal variant, considered in the works of F. G. Glik [14], should be distinguished. The development of this approach can be traced in the works of S. Yu. Olkhovsky and V. V Yavorsky [16]. Scientists have proposed more detailed dependencies and algorithms that allow a number of additional criteria to be taken into account when adjusting the route network. The ideas applied in this approach formed the basis of the methodology [4] proposed by the authors of the article.

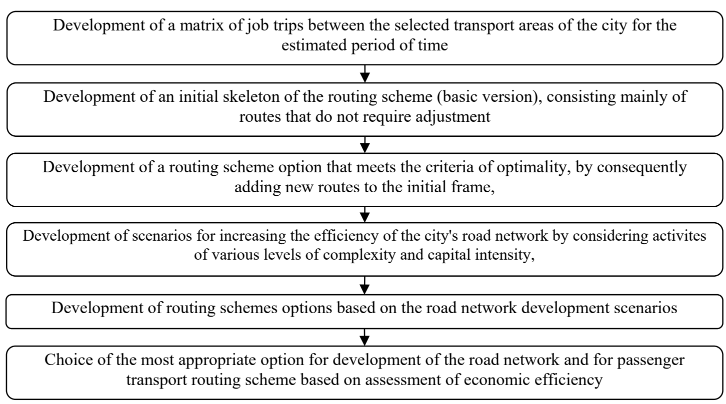
The considered methodology is based on the analysis of the matrix of trips not served by routes included in the original basic framework. The subsequent formation of a new candidate route consists in choosing its base corresponding to the most straightforward chain from the table of unrealized links with the highest value of passenger traffic. Further actions are to build up the base under consideration by adding the most suitable links to it. In this case, all connections that partially coincide with the base of the route being formed are considered, from which several variants of combined chains are further constructed. Depending on location of the base of the route relative to the central part of the city, the build-up of connections to the original chain is performed in one direction or in different directions, consistently approaching the intended end points. For each superimposed chain, which is now considered as a new base of the route, the process of building connections is repeated (Pic. 2). Based on the resulting «tree» of chains, a set of variants of the projected route is formed




***Pic. 2. Formation of variants of combined chains (authors' scheme).***




*Pic. 3. Formation of a subset of variants of the projected route (authors' scheme).*




*Pic. 4. The sequence of designing the passenger transport routing scheme, considering improvement of operational characteristics of the city's road network regarding its use for transport purposes (authors' scheme).*

(Pic. 3). As a result of a directed search, the most rational option is selected, considering optimization criteria (Table 1), which will subsequently be included in the rational routing scheme.

The most rational variant of the route under consideration is identified in accordance with the adopted optimality criterion, chosen from the set of criteria that follows: average passenger travel time $t_{av}$, route length $l_r$, non-straightness coefficient of trips $K_n$, utilization rate of provided seats [occupancy] $K_{use}$. The procedure for including new routes into the initial framework is repeated until all possible trips have been implemented. At the same time, it is necessary to try to ensure that the number of transfers between disconnected areas does not exceed one. The process of designing a routing scheme is considered complete if it fully meets all the necessary conditions.

The use of combinatorial analysis with directed selection of variants allows obtaining a single variant of the routing scheme, which is close to optimal in terms of its indicators. The formation of various options for routing schemes can be based on alternative scenarios for development of the city's transport network. The choice of the most preferable variant of the routing scheme is carried out based on optimality criteria selected above. In this case, the most significant criterion is travel time.

The main stages of designing a rational routing scheme, considering development of the city's main network, are shown in Pic. 4.

**Conclusions.** Considering the routing experience accumulated over a long period of time, an approach has been developed to improve the bus routing scheme for the conditions of a large city, in relationship with the operational state of the road network regarding its use for transport purposes. In contrast to the previously developed methods, the proposed approach considers optimization criteria, which make it possible to comprehensively evaluate the efficiency of routing schemes. Its essence lies in the «gluing» of individual links of the transport network and in sequential developing of a set of competing route options, one of which will later be included in the rational routing scheme. At the final stage of the proposed algorithm, alternative variants of rational routing schemes based on scenarios for development of the city's transport infrastructure are developed. This will ensure an increase in speed of the entire traffic flow and, as a result, reduce the non-productive travel time.

Further research will be aimed at clarifying the dependencies and the algorithm for calculating speed of transportation for various types of passenger transport. At the same time, it is supposed to consider more comprehensively the factors that determine the technical condition of the road network, the characteristics of traffic flows, including their combinations. In addition, soon, it is planned to study the possibility of automating the proposed calculation procedures using specialized software for transport planning and modelling (PTV Visum).

## REFERENCES


1. Buneev, V. M., Novoselov, V. I., Putilova, N. N. Efficiency of urban passenger transport: methods of assessment and justification [*Effektivnost' gorodskogo passazhirskogo transporta: metody otsenki i obosnovaniya*]. Novosibirsk, NGAVT publ., 2008, 415 p.

2. Efremov, I. S., Kobozev, V. M., Yudin, V. A. Theory of urban passenger transportation [*Teoriya gorodskikh passazhirskikh perevozok*]. Moscow, Vysshaya shkola publ., 1980, 535 p.

3. Spirin, I. V. Scientific foundations of the complex restructuring of urban passenger transport: Monograph [*Nauchnie osnovy kompleksnoi restrukturizatsii gorodskogo passazhirskogo transporta: Monografiya*]. Moscow, ICF «Catalogue», 2007, 200 p.

4. Burlutsky, A. A. Ensuring the efficiency of operation of the road network of a large city on the basis of its interaction with the flows of passenger transport (on the example of Tomsk) [*Obespechenie effektivnosti funktsionirovaniya dorozhnoi seti krupnogo goroda na osnove ee vzaimodeistviya s potokami passazhirskogo transporta (na primere g. Tomska)*]. Tomsk, 2015, 196 p. [Electronic resource]: https://www.dissercat.com/content/obespechenie-effektivnosti-funktsionirovaniya-dorozhnoi-seti-krupnogo-goroda-na-osnove-uchet. Last accessed 21.05.2020.

5. Vuchik, V. R. Transport in cities convenient for life. [Russian ed., transl. from English by A. Kalinin]. Sc. ed. M. Blinkin. Moscow, Territory of the future, 2011, 576 p.

6. PIARC: 20th World Road Congress. Montreal, 3–9 September, 1995. Transportation and Urban Space Planning. National Reports, 1995, 487 p.

7. Taylor, B. D. Rethinking Traffic Congestion. Institute of Transportation Studies, University of California, Los Angeles, *ACCESS*, 2002, No. 21, 9 p.

8. Fishelson, M. S. Determining the optimal level of development of the route system of urban passenger transport [*Opredelenie optimalnogo urovnya razvitiya marshrutnoi sistemy gorodskogo passazhirskogo transporta*]. In: Problems of complex development of urban transport systems. abstracts of reports and messages of the all-Union scientific-technical seminar (Minsk, May 17–19, 1978). Minsk, 1978, pp. 135–138.

9. Wohl M., Martin, B. V. Traffic system analysis [Russian ed., short. transl. from English]. Moscow, Transport publ., 1981, 516 p.

10. Transportation and traffic engineering handbook. Ed. by John E. Baerwald, Matthew J. Huber, Louis E. Keefer. [Russian title: Road transportation and traffic management: Handbook. *Avtomobilnye perevozki i organizatsiya dorozhnogo dvizheniya: spravochnik*. Transl. from English.]. Moscow, Transport publ., 1981, 592 p.

11. Trofimenko, Yu. V., Yakimov, M. R. Transport planning: development of efficient transport systems in large cities: Monograph [*Transportnoe planirovanie: formirovanie effektivnykh transportnykh system krupnykh gorodov: Monografiya*]. Moscow, Logos publ., 2013, 464 p.

12. Mikhailov, A. Yu., Golovnykh, I. M. Modern trends in design and reconstruction of street and road network of cities [*Sovremennie tendentsii proektirovaniya i rekonstruktsii uchichno-dorozhnoi seti gorodov*]. Novosibirsk, Nauka publ., 2004, 267 p.

13. Burlutsky, A. A., Korenev, V. I., Guseva, U. Yu. Urban planning aspects of development of a transport scheme in the historical centre of Tomsk [*Gradostroitelnie aspekty formirovaniya transportnoi skhemy v istoricheskom tsentre Tomska*]. *Bulletin of TSUAB*. Tomsk, TSUAB publ., 2018, Iss. 1, pp. 128–139. [Electronic resource]: https://cyberleninka.ru/article/n/gradostroitelnye-aspekty-formirovaniya-transportnoy-shemy-v-istoricheskom-tsentre-g-tomska-1/pdf. Last accessed 21.05.2020.

14. Glik, F. G. Interactive design of the routing system of urban passenger transport [*Interaktivnoe konstruirovanie marshrutnoi sistemy gorodskogo passazhirskogo transporta*]. *Gradostroitelstvo*. Kiev, Budivelnik, 1987, Iss. 39, pp. 100–106.

15. Khrushchev, M. V. Methods of general and local routing of bus transport in cities: Monograph [*Metody obshchei i lokalnoi marshrutizatsii avtobusnogo transporta v gorodakh: Monografiya*]. Moscow, Gos. un-t upr., 1999, 168 p.

16. Olkhovsky, S. Yu., Yavorsky, V. V. Modeling the functioning and development of routed systems of urban passenger transport: Monograph [*Modelirovanie funktsionirovaniya i razvitiya marshrutizirovanykh system gorodskogo passazhirzskogo transporta: Monografiya*]. Omsk, Publishing house SibADI, 2001, 138 p.

17. Vaksman, S. A., Gerasimov, N. M., Slepukhina, I. A. Information technologies in management of urban public passenger transport: Monograph [*Informatsionnie tekhnologii v upravlenii gorodskim obshchestvennim passazhirskim transportom: Monografiya*]. Yekaterinburg, 2012, 258 p.

18. Dimitrov, S., Ceder, A., Chowdhury, S., Monot, M. Modeling the interaction between buses, passengers and cars on a bus route using a multi-agent system. *Transportation Planning and Technology*, 2017, Vol. 40, No. 5, pp. 592–610. DOI: https://doi.org/10.1080/03081060.2017.1314504.

19. SP 42.13330.2016 [Construction rules] Urban planning. Planning and development of urban and rural settlements. Updated edition of SNiP 2.07.01-89*. Moscow, Standartinform, 2017, 90 p. [Electronic resource]: http://docs.cntd.ru/document/456054209. Last accessed 21.05.2020. ●