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Methods of Selection of Transport Interchange Hubs Location Based on Optimization Mathematical Model

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ABSTRACT

The article discusses development of a system of transport and interchange hubs (TIH). The need to create TIHs is due to an opportunity to increase efficiency of passenger flows in the urban public transport system, to reduce travel time for passengers, to ensure comfortable and safe conditions for transfer, and to improve quality of service to the population.

The objective of the research is to develop methods that allow solving the problem of optimal selection of TIH locations in any city according to the economic criterion and the criterion of the average travel time using the methods of mathematical modelling. The technique comprises search for optimal travel routes in the city and identification of effective interchange hubs using the developed software product called «Efficient transfers». Efficient transfer hubs with maximum passenger traffic are candidates for TIH locations. The work describes calculations made according the proposed methods and optimal options for location of this in the city of Samara considering limited funds, reduction in travel time and in the number of passengers using these TIHs. The research also resulted in obtaining the dependence of reduction in the average time of an urban trip on the number of TIHs.

Keywords: *transport and interchange hub, urban transport network, public transport, passenger flow, average travel time, optimization mathematical model.*

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Background.

The need to create transport interchange hubs is due to the opportunity to increase the efficiency of organizing passenger flows in the urban public transport system, to improve quality of services to the population, to increase attractiveness of urban public transport [1–6]. The topics of providing better transport accessibility, improving quality of transport services to the population, increasing the role of urban public transport, reducing average travel time (which is possible due to development of systems of transport interchange hubs) are among most important issues in the Transport Strategy of the Russian Federation for the period up to 2030 [7].

In each case it is important to select the type of TIH, the modes of transport interacting in the hub, to design each element of the interchange so that it could provide a fast, safe transfer along with high level of passenger service [8–10].

The optimal selection of location of transport and interchange hubs (TIH) will increase demand for urban public transport, reduce travel time due to the use of optimal routes by passengers, provide comfortable, safe conditions for transfer, and facilitate acquisition by passengers of accompanying services provided by social facilities [11; 12].

Global practices show that development of TIHs is often linked to off-street stations of rapid transit, which is associated with the developed system of urban railways and underground (metro) [1; 3; 4; 9; 13; 14]. Following the example of foreign cities, TIHs are being built in Moscow [15] and St. Petersburg [16]. However, it is important to develop a universal methodology for determining the number and locations of TIHs, which will make it possible to develop a system of transfer hubs even for cities with an insufficiently developed off-street transport system, but a developed system of urban land transport.

The problem of choosing the number and location of transfer hubs was considered by Russian researchers: D. N. Vlasov [11; 17–19], A. A. Shagimuratova [20; 21], N. A. Kalyuzhny [22–25], M. A. Piir [26; 27].

D. N. Vlasov [11; 17; 18] proposed to determine priority (high-priority) TIHs using qualimetry. The author notes a number of urban planning factors influencing the selection of a construction site for transfer hubs, considering provision of ecological sustainable development of the urban environment [19].

A. A. Shagimuratova [20; 21] has developed a methodology for selecting priority TIHs developed with participation of railway transport, by calculating the rating of each of them based on expert assessments.

N. A. Kalyuzhny [22–25] selects priority TIHs on the criterion of resistance to changes in passenger flows. The author examines the junctions developed around metro stations and suburban (commuter) railways. An important criterion for choosing junctions as possible future TIH is the rate of influence of the delays on the size of passenger flows. Besides, the value of this coefficient and its determining role in the selection of transfer hubs in the work are not substantiated.

The method for determining the optimal number of TIHs in cities and megacities, proposed by M. A. Piir [26; 27], is based on the calculation of the number of transfer hubs depending on the area of the city and the zone of influence of TIHs. However, the method involves calculating the number of junctions without determining their locations, does not take into account the specifics of the growth of modern cities and megalopolises.

Consequently, the issue of determining the number and selecting locations of transfer hubs requires further study. It is necessary to carry out a comprehensive analysis of the urban transport network and the needs of passengers, to determine the main criteria that will allow to develop a TIH system of any city in such a way as to achieve the maximum social and economic effect [12; 28].

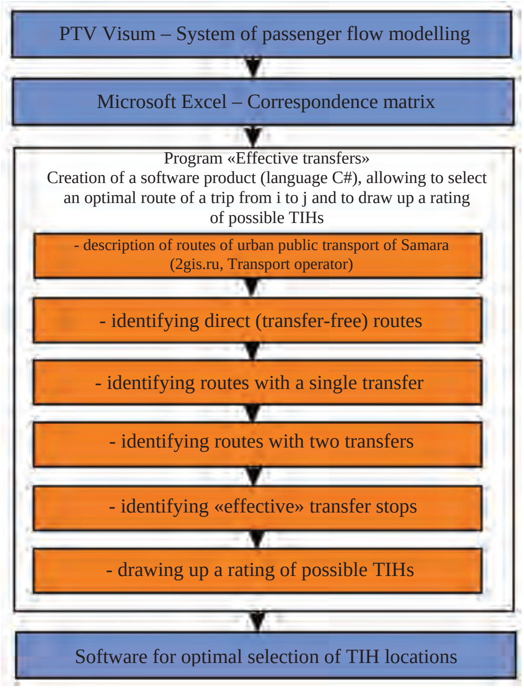
The *objective* of the research is to develop methods for determining the number and location of TIHs in any city using the economic criterion and the criterion of the average travel time and applying an optimization mathematical model.

Results.

The application of proposed methods includes three stages:

• *1 stage*. Studying the needs of passengers in terms of transportation services, calculating the amount of passenger flow, compiling a matrix of inter-stop correspondence.

• *2 stage*. Selection of optimal routes for passengers within the urban public transport



Pic. 1. Software products used to implement the algorithm for selection the location of transport interchange hubs.

Table 1

Fragment of an inter-stop correspondence matrix $C^0 = \{c^0(i, j)\}$

Number of a departure stop, *i*	Number of an arrival stop, *j*	Average daily passenger flow $c_{i,j}$, pass.
1	2	2
1	3	3
....		
1006	1004	1
1006	1005	71

system; determination of «effective» transfer hubs, in which transfers are carried out; drawing up their rating according to the criterion of the size of passenger flow.

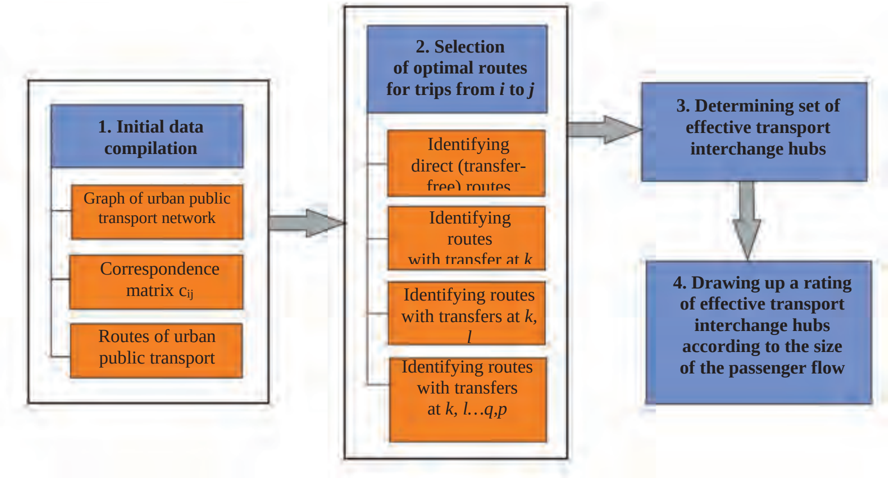
• *3 stage.* Selection of TIHs locations based on an optimization mathematical model using the economic criterion or the criterion of the average standard travel time.

To implement the proposed methods, well-known and developed software products are used. The software products used to implement the algorithm for selection of locations of TIHs are shown in Pic. 1.

The problem of choosing the location of transport interchange hubs is considered from the point of view of the general criterion which is average travel time of passengers in the urban public transport system [12; 22–25; 28; 29].

At the first stage, the analysis of the urban transport system is carried out [29; 30], demand for public transport is studied, the correspondence matrix is calculated. The division of the urban area into zones and the automated calculation of the interdistrict correspondence matrix were considered in the works of O. N. Saprykin [31; 32], M. R. Yakimov [33; 34]. However, for implementation of the proposed methods for selection of TIH locations, it is important to obtain an inter-stop correspondence matrix, considering accessibility of each stop of public transport [12; 29].

Interdistrict correspondence matrix obtained by mathematical modelling (using the gravity model in PTV Visum) is recalculated [32; 33] into the inter-stop correspondence matrix



Pic. 2. Block diagram of the algorithm for calculating effective interchange hubs.

$C^0 = \{c^0(i,j)\}$, using a simplified urban transport network of public transport, where the number of stops is reduced by grouping some stops of the line of one and the same route [12; 28].

The inter-stop correspondence matrix $C^0 = \{c^0(i, j)\}$ shows the average daily number of passengers who travel from stop *i* to stop *j* along the urban network with public transport. A fragment of the interstop correspondence matrix $C^0 = \{c^0(i, j)\}$ is shown in Table 1.

At the second stage, the selection of optimal routes for passengers within the urban public transport system is carried out according to the criterion of the minimum travel time, efficient transfer hubs are determined, and their rating is compiled according to the criterion of passenger flow. The block diagram of the algorithm for calculating effective transfer hubs is shown in Pic. 2.

With an inter-stop correspondence matrix $C^0 = \{c^0(i, j)\}$ (Table 1) and a simplified urban transport network of public transport, the routes for passengers traveling from *i* to *j* are determined. Some passengers use well-known, familiar routes for themselves, especially for traveling to job location and back. Another part of passengers uses special software and applications to choose the route of the trip. The choice of the route is based on the choice of a direct (non-stop, transfer-free) route, which is associated with unwillingness to pay for travel twice, as well as with inconvenience of the transfer itself. However, this takes a lot of time for a long walking approach to the desired departure and arrival stop.

We believe that there is a single system of payment for the trips, that is, for example, within an hour a passenger travels through the urban public transport network with one and the same ticket, regardless of the number of transfers and the types of urban transport used. When choosing the route for the trip, the passenger makes a decision based on time spent on the trip, considering comfortable, safe conditions of transfer and possibility to get accompanying social services, and on a possibility to pay the fare only once, even if he uses several types of urban public transport.

To solve the problem of choosing the optimal route for a trip from *i* to *j*, the software product «Effective transfers» was developed in C# (Microsoft Visual Studio 2017 development environment), which allows you to choose an optimal route from *i* to *j*: whether it is direct (if there is any), or it provides for a single or more transfers. As a result, we get the locations where the largest transfer hubs in terms of the number of passengers are located. Exactly those interchange hubs of passenger transport should be considered as candidates for location of transport interchange hubs.

For each route with a single change, out of the whole set of possible interchange junctions *k*, such interchange hub *r* is found that provides the minimum travel time from *i* to *j*:

$$t_{i,r,j} = \min_k t_{i,k,j}. \qquad (1)$$

Going through the options, we get a single or more equivalent transfer hubs. Using Effective transfers software, we obtain a list of all hubs *r* where transfer is performed. Let's call them effective transfer hubs. We calculate the capacity of those hubs. The capacity means the maximum possible number of

Table 2

Rating of effective interchange hubs of the urban district of Samara according to the value of passenger flow c_r

No.	No. of a stop	Name	Average daily passenger flow (c_r), pass.
1	122	Railway station	92154,5
2	183	Bus station Aurora	88150,76
3	257	Kirova sq.	78206,33
4	163	Barboshina Polyana	76829,26
5	292	Galaktionovskaya (Krasnoarmeiskaya str.)	71891
6	46	Novo-Vokzalnaya (Moskovskoe highway)	69064,28
7	265	Moskovskoe highway (Tashkentskaya str.)	68801,35
8	220	pr. Metallurgov (Sovetskaya str.)	63937,97
9	269	Pobeda	62279,45
10	60	Stara-Zagora (pr.Kirova)	60913,49
11	133	Polevaya	60003,01
12	297	Railway station	59221,62
13	323	Bus station Volskaya	57061,23
14	236	Tukachevskogo	54994,64
15	199	Dom pechati	53717
16	47	Novo-Vokzalnaya (Stara-Zagora str.)	52732,45
17	266	Stara-Zagora (Tashkentskaya str.)	51049,21
18	213	Bezymyanka	50647,14
19	212	Volskaya	48198,67
20	143	Dachnaya (tram)	47989,96
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271	155	Ufimskaya	96,73184
272	314	GATP-3	84,437

passengers who will use this effective transport interchange hub *r*:

$$c_r = \sum_{i,j} c_{i,r,j} + \sum_i c_{ir} + \sum_j c_{rj},\ r = 1, 2, ...R, \qquad (2)$$

where $\sum_{i,j} c_{i,r,j}$ is the number of passengers, making transfers in *r*-th effective transfer interchange hub;

$\sum_i c_{ir}$ is the number of passengers coming to *r-th* effective transport interchange hub (it is the same as *j*);

$\sum_j c_{rj}$ is the number of passengers, departing from *r*-th effective transport interchange hub (it is the same as *i*).

Then we draw up a rating of effective transport interchange hubs according to the intensity of passenger flow (the value c_r).

At the third stage, selection of TIH locations is carried out on the basis of an optimization mathematical model according to the economic criterion or the criterion of average standard travel time.

Considering the economic approach to selection of TIH locations, we set the cost S_r for construction of each specific TIH. The development of TIHs is aimed at improving convenience of servicing passengers when transferring and requires significant costs for redevelopment of the territory, construction of convenient crossings and additional infrastructure (retail outlets, waiting areas, etc.).

Creation of TIH should lead to a decrease in time spent by passengers on total service. That is, when creating TIH, it is important to reduce travel time by reducing each t_{irj} and, consequently, average travel time through the system of TIHs.

It is necessary to allocate funds E_0 for creation of transport interchange hubs selected

257 Optimal option of location of TIH when E_o = 2,5 bln rub.

257 + 122 Optimal option of location of TIH when E_o = 3,0 bln rub.

257 + 280 Optimal option of location of TIH when E_o = 3,5 bln rub.

Pic. 3. Optimal options for location of TIHs in Samara considering limited funds, reduction in travel time and the number of passengers using the selected TIHs.

from a possible set of effective interchange hubs (candidates for the role of TIH). In this case, it is necessary to achieve the maximum reduction in average travel time through TIH system for a given E_0. We get an optimization problem of linear Boolean programming, where Boolean variables $x_r = 1$, if the r-th junction will have a TIH, and $x_r = 0$ otherwise [12; 28]:

$$\Delta T = \frac{1}{\sum_r c_r} \sum_r c_r \Delta t_r x_r \to \max, \quad (3)$$

$$\sum_r S_r x_r \le E_0. \quad (4)$$

Solving problems (3), (4), we shall select among all effective transfer hubs those in which we will build transport interchange hubs.

Each effective transfer hub r is crossed by one or more routes with interchange at r. For each such route with an interchange, travel time is determined. Comparing travel time before and after determining the optimal route, we obtain a reduction in time of this trip through the considered interchange r. If several interchange routes N pass through r, then for each r the average travel time reduction Δt_r is determined.

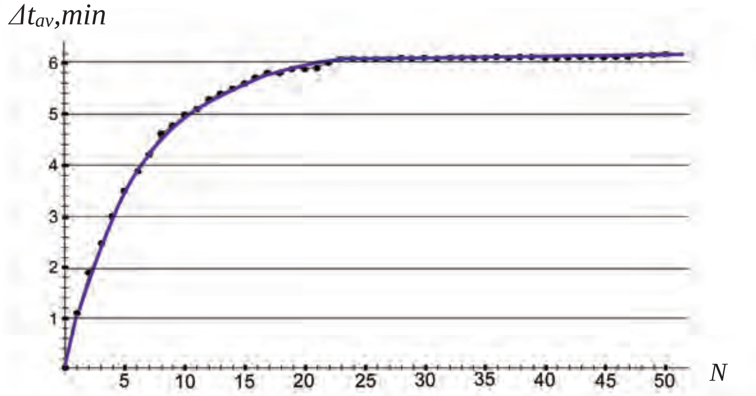
Let us consider the solution to the problem of selecting locations of TIHs using the criterion of average travel time. Knowing the value of reduction in average time of a single trip with a transfer (Δt_r) at the hub r, if it is equipped with TIH, it can be required that the selection of the system of transfer junctions ensures the maximum reduction in average time of a trip around the city Δt_{av}:

$$\Delta t_{av} = \frac{1}{(\sum_{ij} c_{ij} + \sum_r c_r)} \sum_r c_r \Delta t_r x_r \to \max, \quad (5)$$

where c_{ij} is the number of passengers, who travel from i to j using transfer-free routes.

Approbation of the technique of optimal selection of location of TIHs in Samara urban district made it possible to identify 272 effective interchange hubs that are candidates for the role of TIH.

Since we believe that the values of c_r determine the main criterion for creation of interchange hubs [12; 28], then the effective



Pic. 4. Dependence of reduction of average travel time of a trip in the city tav on the number of TIH N.

interchange hubs are ranked in descending order of c_r (Table 2).

Considering the economic approach to selection of transfer hub locations, the optimal options for the location of TIHs in Samara were obtained, which are shown in Pic. 3.

Having solved the problem of selection of locations of TIHs according to the criterion of average standard travel time, we acquire the dependence of reduction in average time of a trip in the city Δt_{av} on the number of TIH N (Pic. 4).

It should be noted that the value Δt_{av} reaches the limit value of 6 minutes. With a further increase in the number of TIHs, average travel time in the city t_{av} will be practically unchanged.

Conclusions.

Thus, the developed methods allow solving the problem of selection of the locations of TIHs. The technique comprises the search for optimal routes for traveling within the city and identification of effective interchange hubs using the developed «Effective transfers» software product. Efficient transfer hubs with maximum passenger traffic are candidates for TIH location. Further, on the basis of a mathematical model, the optimal selection of the number and of locations of TIHs in any city is carried out based on data on the volume of passenger flow, average travel time between stops, the number of stops of the transport network, and the cost of building each TIH.

REFERENCES

1. Monzón, A., Hernández, S., Di Ciommo, F. Efficient urban interchanges: The City-HUB model. *Transportation Research Procedia*, 2016, Vol. 14, pp. 1124–1133. DOI: https://doi.org/10.1016/j.trpro.2016.05.183.

2. Graham-Rowe, E., Skippon, S., Gardner, B., Abraham, C. Can we reduce car use and, if so, how? A review of available evidence. *Transportation Research Part A: Policy and Practice*, 2011, Vol. 45, Iss. 5, pp. 401–418. DOI: https://doi.org/10.1016/j.tra.2011.02.001.

3. Kristersson, P. The role of public transport interchanges in regional planning. *Regions Magazine*, January 2012, Vol. 285, Iss. 1, pp. 16–17.

4. Di Ciommo, F., Monzón, A., Barberan, A. Interchange place: Sustainable and Efficient Urban Transport Interchanges. In the book: CITY-HUBs, March 2016, pp. 37–50. DOI: 10.1201/b19519-5.

5. Hernandez, S., Monzon, A., de Oña, R. Urban transport interchanges: A methodology for evaluating perceived quality. *Transportation Research Part A*, 2016, Vol. 84, pp. 31–43. DOI: https://doi.org/10.1016/j.tra.2015.08.008.

6. Redman, L., Friman, M., Gärling, T., Hartig, T. Quality attributes of public transport that attract car users: A research review. *Transport Policy*, 2013, Vol. 25, pp. 119–127. DOI: https://doi.org/10.1016/j.tranpol.2012.11.005.

7. Transport strategy of the Russian Federation for the period up to 2030: official text of resolution of Government of the Russian Federation of November 22, 2008 No. 1734-r: as of 11.06.2014 [*Transportnaya strategiya Rossiiskoi Federatsii na period do 2030 goda: ofits. tekst raspor. Pravitelstva RF ot 22 noyabrya 2008 g. № 1734-r: na 11.06.2014*]. [Electronic resource]: http://government.ru/dep_news/13190/. Last accessed 05.02.2020.

8. Di Ciommo, F., Vassallo, J.M., Oliver, A. Private Funding of Intermodal Exchange Stations in Urban Areas: Case of Madrid, Spain. *Transportation Research Record*, January 2009, Vol. 2115, Iss. 12, pp. 20–26. DOI: https://doi.org/10.3141/2115–03/.

9. Pitsiava-Latinopoulou, M., Iordanopoulos, P. Intermodal Passengers Terminals: Design Standards for Better Level of Service. *Procedia – Social and Behavioral Sciences, Transport Research Arena*, 2012, Vol. 48, pp. 3297–3306. DOI: https://doi.org/10.1016/j.sbspro.2012.06.1295.

10. Dell'Asin, G., Monzón, A., Lopez-Lambas, M. E. Key quality factors at urban interchanges. *Proceedings of the ICE – Transport*, 2014, pp. 1–10. DOI: https://doi.org/10.1680/tran.13.00039.

11. Vlasov, D. N. Transport interchange hubs: Monograph [*Transportno-peresadochnie uzly: Monografiya*]. 2nd ed. Moscow, MGSU publ., 2017, 192 p.

12. Leonova, S. A. Choice of locations of interchange hubs of the urban passenger transport network [*Vybor mest raspolozheniya peresadochnykh uzlov seti gorodskogo passazhirskogo transporta*]. *Transport Urala*, 2019, Iss. 4 (63), pp. 101–105.

13. Li, Zhi-Chun; Lam, W. H. K.; Wong, S. C. Modeling intermodal equilibrium for bimodal transportation system design problems in a linear monocentric city. *Transportation Research Part B*, 2012, Vol. 46, Iss. 1, pp. 30–49. DOI: https://doi.org/10.1016/j.trb.2011.08.002.

14. Liu, Li Fen; Wang, Wen. Analysis of Urban Rail Transit Seamless Transfer Standard. MATEC Web of Conferences 81, 03002, 2016. [Electronic resource]: https://www.matec-conferences.org/articles/matecconf/pdf/2016/44/matecconf_ictte2016_03002.pdf. Last accessed 05.02.2020. DOI: 10.1051/matecconf/20168103002.

15. Resolution of Moscow Government dated September 6, 2011 No. 413-PP «On the development of transport interchange hubs in the city of Moscow» [*Postanovlenie Pravitelstva Moskvy ot 06 sentyabrya 2011 g. № 413-PP «O formirovanii transportno-peresadochnykh uzlov v gorode Moskve»*]. [Electronic resource]: http://docs.cntd.ru/document/537907102. Last accessed 05.02.2020.

16. Strategy for development of the transport system of St. Petersburg and Leningrad region for the period up to 2030 [*Strategiya razvitiya transportnoi sistemy Sankt-Peterburga i Leningradskoi oblasti na period do 2030 goda*]. [Electronic resource]: http://www.spbtrd.ru/program-development/. Last accessed 05.02.2020.

17. Vlasov, D. N. Priorities of development of the system of transport interchange hubs of an agglomeration [*Prioritetnie napravleniya razvitiya sistemy transportno-peresadochnykh uzlov v aglomeratsii*]. *Academia. Architecture and construction*, 2013, Iss. 3, pp. 86–89.

18. Vlasov, D. N. Structure and composition of regulatory requirements for urban transport interchange hubs [*Struktura i sostav normativnykh trebovanii k gorodskim transportno-peresadochnym uzlam*]. *Gradostroitelstvo*, 2015, Iss. 3 (37), pp. 11–19.

19. Sherbina, E. V., Danilina, N. V., Vlasov, D. N. City planning issues for sustainable development. *International Journal of Applied Engineering Research*, 2015, Vol. 10, No. 22, pp. 43131–43138. [Electronic resource]: http://www.ripublication.com/Volume/ijaerv10n22.html. Last accessed 05.02.2020.

20. Shagimuratova, A. A. System analysis in determining the priority directions of development of transport interchange hubs of railway transport [*Sistemniy analiz i opredelenie prioritetnykh napravlenii razvitiya transportno-peresadochnykh uzlov zheleznodorozhnogo transporta*]. *Gradostroitelstvo*, 2016, Iss. 2 (42), pp. 63–71.

21. Shagimuratova, A. A. Methodology for assessing development of transport interchange hubs of railway transport [*Metodika otsenki razvitiya transportno-peresadochnykh uzlov zheleznodorozhnogo transporta*]. *Internet journal «Naukovedenie»,* 2017, Vol. 9, Iss. 1. [Electronic resource]: http://naukovedenie.ru/PDF/58TVN117.pdf. Last accessed 05.02.2020.

22. Kalyuzhny, N. A. Methods for optimizing location of transport interchange hubs in the system of urban passenger transport. Ph.D. (Eng) thesis [*Metodika optimizatsii razmeshcheniya transportno-peresadochnykh uzlov v sisteme gorodskogo passazhirskogo transporta. Dis... kand. tekh. nauk*]. St. Petersburg, PGUPS publ., 2019, 254 p.

23. Bulycheva, N. V., Kalyuzhny, N. A., Losin, L. A. Models of location of transport interchange hubs of urban passenger transport [*Modeli razmeshcheniya transportno-peresadochnykh uzlov gorodskogo passazhirskogo ransporta*]. *Finansy i biznes*, 2018, Iss. 1, pp. 54–63.

24. Kalyuzhny, N. A. Justification of the priority of location of transport interchange hubs in the structure of the agglomeration by the method of mathematical modelling [*Obosnovanie prioritetnosti mest razmeshcheniya transportno-peresadochnykh uzlov v structure aglomeratsii metodom matematicheskogo modelirovaniya*]. *Vestnik grazhdanskikh inzhenerov*, 2017, Iss. 5 (64), pp. 142–148.

25. Kalyuzhnyi, N., Losin, L. A method of mathematical modeling for transfer hub establishment in Saint Petersburg. *Transportation Research Procedia*, 2018, Vol. 36, pp. 245–251. DOI: 10.1016/j.trpro.2018.12.075.

26. Piir, M. A. Determination of the required number of transfer hubs while developing an integrated transport system of a large city [*Opredelenie neobkhodimogo kolichestva peresadochnykh uzlov pri formirovanii kompleksnoi transportnoi sistemy krupnogo goroda*]. *Proceedings of the second Sverdlovsk scientific and practical conference «Current state and development prospects of transport systems in a large city» / Sverdlovsk Institute of National Economy, 1974, Iss. 1. Methodological aspects of research and design of transport systems of cities and agglomerations. Studies of the patterns of settlement and movement of the population in cities and agglomerations*, pp. 21–24.

27. Piir, M. A. Issues of development of a system of passenger transport in a large city [*Voprosy formirovaniya sistemy passazhirskogo transporta krupnogo goroda*]. *Practice of development and implementation of master plans of cities*. Kiev, Budivelnik publ., 1975, p. 96.

28. Leonova, S. A. Optimal choice of locations for transport interchange hubs [*Optimalniy vybor mest raspolozheniya transportno-peresadochnykh uzlov*]. *Transport and logistics: strategic priorities, technological platforms and solutions in the globalized digital economy. Proceedings of 3rd international scientific and practical conference*, Rostov-on-Don, 2019, pp. 214–216.

29. Chao, Sun; Xiaohong, Chen; H. Michael Zhang, and Ze Huang. An Evaluation Method of Urban Public Transport Facilities Resource Supply Based on Accessibility. *Hindawi Journal of Advanced Transportation*, Vol. 2018, Article ID3754205, 11 p. DOI: https://doi.org/10.1155/2018/3754205.

30. Fedorov, V. P., Pakhomova, O. M., Losin, L. A., Bulycheva, N. V. Analysis of the problems of the transport system of the center of a large city: the experience of using methods of mathematical modeling [*Analiz problem transportnoi sistemy tsentra krupnogo goroda: opyt primeneniya metodov matematicheskogo modelirovaniya*]. *Management of territory development*, 2009, Iss. 4, pp. 18–25.

31. Ludan, I., Maiorov, E., Santana, J. D. M., Saprykin, O. Integrated approach to building a microscopic city model. In Proceedings of the 5th International Young Scientists Conference on Information Technologies, Telecommunications and Control Systems, 2018, 8 p.

32. Saprykin, O., Saprykina, O. Multilevel Modelling of Urban Transport Infrastructure. In Proceedings of the 1st International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS-2015). Portugal, Lisbon, SCITEPRESS, 2015, pp. 78–82.

33. Yakimov, M. R. Transport planning: creating transport models of cities: Monograph [*Transportnoe planirovanie: sozdanie transportnykh modelei gorodov: Monografiya*]. Moscow, Logos publ., 2013, 188 p.

34. Yakimov, M. R., Arepyeva, A. A. Transport planning. Features of modeling traffic flows in large Russian cities: Monograph [*Transportnoe planirovanie. Osobennosti modelirovaniya transportnykh potokov v krupnykh rossiiskikh gorodakh*]. Moscow, Logos publ., 2016, 280 p.