ORIGINAL ARTICLE
DOI: https://doi.org/10.30932/1992-3252-2023-21-6-2

World of Transport and Transportation, 2023, Vol. 21, Iss. 6 (109), pp. 183–190

Approaches to Methodological Rationale of Development of Single Backbone Transport Network and Prioritisation of Transport Infrastructure Development Projects

Arthur V. KARLOV

Oleg V. EVSEEV

***Arthur V. Karlov*[1], *Oleg V. Evseev* [2]**

[1] Russian University of Transport, Moscow, Russia.
[2] Scientific Centre for Complex Transport Problems of the Ministry of Transport of the Russian Federation, Moscow, Russia.
[1] ORCID 0000-0001-7147-8501; Russian Science Citation Index SPIN-code: 1409–3481; Russian Science Citation Index Author ID: 1080516.
[2] ORCID 0000-0002-2437-6497; Scopus Author ID 57215525670; Russian Science Citation Index SPIN-code: 9447-9075; Russian Science Citation Index Author ID: 187.
✉ [1] karlov@edu.rut-miit.ru.

ABSTRACT

The article discusses approaches to rationale of the development of the Single Backbone Transport Network (SBTN), political, scientific and mathematical prerequisites for identifying key infrastructure elements. The Transport Strategy of the Russian Federation for the period until 2030 with a forecast until 2035 provides basic criteria for each of the backbone networks of modes of transport, while it is highlighted that the development of the SBTN is carried out using transport and economic balance tools. The article explores the possibilities for the practical application of scientific methods in the implementation of state transport policy based on the existing regulatory framework.

Selection of key (backbone) transport infrastructure is proposed to be made with the Kruskal's algorithm, as well as with corresponding optimisation methods using the principles of connectivity, alternativelessness and intensity. Description of the construction of a connected network graph includes description of its edges and vertices as well. Application of the described algorithms results in construction of the segments of the SBTN forming a connected transport network that includes the core transport structural framework of the Single Network, as well as additional sections of the network that ensure the passage of traffic flows with the highest cargo and passenger turnover, which together satisfy the restrictive conditions on financing their maintenance and repair.

The proposed methodology can be used, e.g., in development of transport and economic balance tools, as well as of specialised software for modelling traffic flows.

Thus, the article presents a rationale for providing scientific advice and guidance in implementation of state transport policy intended to improve its quality by promoting an evidence-based approach.

Keywords: transport policy, transport infrastructure, public administration analysis, decision-making methods.

For citation: Karlov, A. V., Evseev, O. V. Approaches to Methodological Rationale of Development of Single Backbone Transport Network and Prioritisation of Transport Infrastructure Development Projects. World of Transport and Transportation, 2023, Vol. 21, Iss. 6 (109), pp. 183–190. DOI: https://doi.org/10.30932/1992-3252-2023-21-6-2.

The text of the article originally written in Russian is published in the first part of the issue.
Текст статьи на русском языке публикуется в первой части данного выпуска.

INTRODUCTION

In 2021, the Government of the Russian Federation approved a new edition of the country's Transport Strategy (hereinafter referred to as the Strategy) intended for the period until 2030 with a forecast until 2035. For the first time ever, the key document of the transport industry has laid the foundations for a system approach to managing the development of the sector: the development of the country's transport system should be carried out based on the priorities, rules and guidelines defined by the Strategy. The provisions of the Strategy are mandatory when making decisions for both the Federal Government and regional authorities, as well as for managers of enterprises in the transport industry.

The Strategy is a tool for implementing transport policy, which, in turn, when implemented with excellence relies on the so-called «evidence-based approach». The scientific studies in the field of public administration methodology considered this issue quite in detail [1], Russian scientists also explored it in relation to certain sectors of the economy [2]. It should be noted that the Strategy lays down the prerequisites for the use of such an approach, as well as of scientific methods in development of state transport policy. Thus, the most important innovation of the Strategy was introduction, definition and detailing of the Single Backbone Transport Network (hereinafter referred to as SBTN). According to the Strategy, the SBTN is «a balanced and connected transport network that combines the most important transport infrastructure facilities for all modes of transport and ensures the functional unity of the transport system, sustainable interconnection and spatial development of the largest populated areas, economic centres, main mineral resource and production zones, geostrategic territories, cultural heritage sites of the Russian Federation, the most popular tourism sites and recreational areas».

The Strategy provides basic criteria for each of the backbone networks of modes of transport, while highlighting that development of the SBTN is carried out using transport and economic balance tools: «Updating and adjusting the general scheme for development of the Single backbone network is carried out based on the transport and economic balance – a set of economic, mathematical and transport models characterising the dependence of demand for transportation and its distribution by mode of transport on economic factors and parameters of infrastructure development».

Thus, the Strategy lays the foundations for applying an «evidence-based approach» to public policy. Similar approaches are being introduced in other sectors of the economy, which is also noted by Russian researchers. Besides, the Strategy has established the basic parameters of transport policy in the field of prioritising the expenditure of budget funds at all levels on modernisation, maintenance and development of certain transport infrastructure. This kind of prioritisation is the basis for further development of economic rationale of decision-making mechanisms in the transport industry and increase in the efficiency of the country's economy, including considering the need to improve the quality of investment decisions [3].

The current geopolitical situation and economic conditions require a transformation of the operating conditions of the transport industry, increase in the efficiency and consistency of state transport policy.

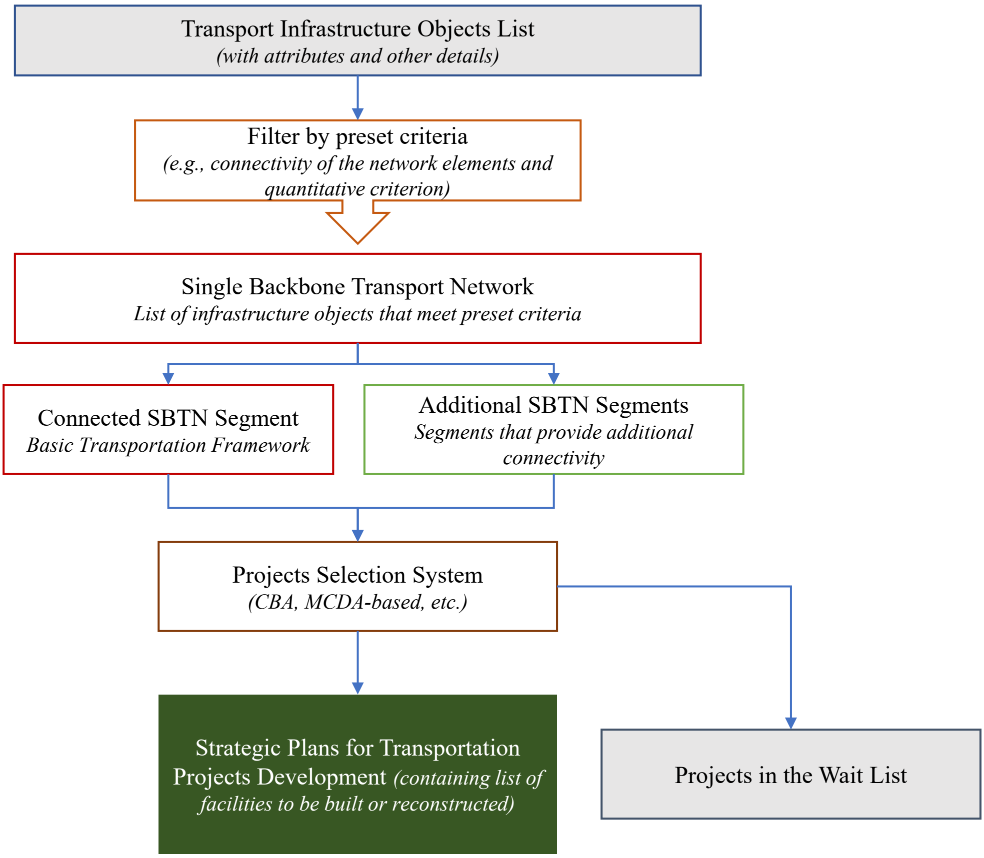
The rate of development of the transport system is directly related to the potential for economic development, which has been noted more than once in scientific studies conducted using various empirical approaches and other assessment methods [4–6].

The existing system of management of development of the transport industry does not fully ensure sufficient interconnection of development tasks of various modes of transport and the primary achievement of the end-to-end goal of ensuring connectivity and optimisation of all types of transport infrastructure, which is necessary for optimal distribution of cargo and passenger flows, considering current challenges and development tasks of the Russian Federation.

It seems that there is a demand for development of a rationale of development of the SBTN, which combines the most important transport infrastructure facilities for all modes of transport and ensures the functional unity of the transport system through the instruments of transport and economic balance, which provides for optimal planning of relevant infrastructure projects.

PROBLEM STATEMENT

Even though the Strategy describes in sufficient detail the criteria for selecting infrastructure facilities and sections for core



Pic. 1. A system for prioritising development projects in the transport industry based on the concept of a Single Backbone Transport Network [chart developed by the authors].

networks by mode of transport, the selection will require further detailing, clarification of the criteria and formalisation of the selection procedure itself to build a connected SBTN graph.

At the same time, it is necessary to establish decision-making procedures about which projects should be selected for the purpose of developing the SBTN. Selection procedures can be based on decision support tools: systems for ranking and selecting projects based on cost-benefit methods and multi-criteria selection [7].

Thus, within the framework of this study and for the purposes of this article, it is proposed to consider a two-stage decision-making system regarding the parameters for development of transport infrastructure in long-term industry development programs:

1. Narrowing of the number of alternatives in the selection procedure: prioritisation and selection of critical and promising infrastructure – its formalisation into the register (lists) of SBTN infrastructure.

2. Selection of measures for development of SBTN infrastructure according to their significance under the conditions of limited funding based on multi-criteria decision and cost-benefit analysis.

The selection procedure is shown schematically in Pic.1.

RESULTS

1. Methodological Approach to Development of SBTN Graph

For the purposes of selecting SBTN objects, we will propose the following methodological approach that clarifies the mechanisms of the Strategy.

The SBTN is divided into segments considering maximisation of operated traffic flows within the limits of restraints on maintenance and repair of transport infrastructure facilities.

Segments are formed in order of increasing volume of traffic flows passing through the network, within the limits of funding for its maintenance and repair.

To determine the boundaries of the SBTN, a network segmentation algorithm is proposed.

1) Segment 1 – the basic transport structural framework of the SBTN – a minimal connected tree of the transport network, covering all key transport zones and ensuring their connectivity with each other. Objects of the basic transport structural framework must be provided with maintenance and repair without fail.

2) Segment 2 and subsequent segments are formed by transport infrastructure objects that are attached to the core transport structural framework and ensure a reduction in transportation distances and time (increasing network connectivity).

The connection is carried out sequentially across levels, based on maximising the traffic flows served by the added objects and satisfying the specified resource limit for maintenance and repair of these objects. The SBTN core transport structural framework with objects added to it forms a general network called the next level segment. The boundaries of the segment are determined by a given budgetary resource limit for maintenance and repair of facilities included in the segment.

3) An increase in the budget constraint on maintenance of SBTN facilities makes it possible to build segments of subsequent levels, each of which will include the previous segment and new transport infrastructure facilities added to it. Thus, segments of different levels are nested within each other. With the transition from level to level, segments gradually capture more and more objects of the SBTN transport infrastructure.

A SBTN segment will be a connected subgraph of the SBTN graph, covering all key transport zones of the territory under consideration. The purpose of dividing the SBTN graph into segments is to determine which subset of SBTN objects should be primarily provided with funding for creation, maintenance and operation throughout the life cycle, which subset of objects should be provided secondarily, and so on according to priorities. In this case, each subset must define an SBTN subgraph that has the property of connectivity. Otherwise, the main function of the Single Backbone Network will not be fulfilled, that is, providing transportation between all transport zones defined for a given study.

Initial list of transport zones:

• Capitals of the constituent entities of the Russian Federation.

• Cities with a population of 100 thousand people or more.

• Airports and alternate airfields necessary for safe operation of airports.

• Railway stations.

• Sea and river ports.

• Checkpoints across the state border.

• Capitals of neighbouring states that have transport connections with the Russian Federation.

• Natural resource exploitation zones.

• Production clusters, centres of economic growth.

• Large objects of tourist attraction.

• Settlements that do not have year-round land communication, except for inland waterways.

• Exclave territories and several territories of geostrategic importance.

• Multimodal transport and logistics centres with sufficient target processing capacity (for example, at least 200 thousand TEU per year), integrated into the SBTN linear infrastructure network, transport and logistics centres created in the format of «cargo villages».

Within the set of indicated transport zone, *key transport zones* are identified, for which a connected single transport network covering them will be found.

Thus, segments are connected subgraphs of the SBTN graph, covering all key transport zones. The connectivity of a graph is determined by the presence of a path along this graph between any pairs of its vertices. Therefore, to solve the problem, it is necessary to determine the key transport zones (nodes of the SBTN graph), on which the SBTN will rely and ensure their connectivity, and then find the edges of the SBTN graph along which it is possible to «travel» from any vertex to any other, that is, the edges that provide graph connectivity. Approaches to such a problem have been considered by several authors [8], but mainly dealt with networks consisting of the infrastructure of one mode of transport.

First, it is advisable to determine the initial subset of SBTN objects – the first basic segment, provided by financing for maintenance and repair, forming a connected subgraph of the SBTN and allowing the largest volume of traffic flows to pass through. The algorithm for constructing the first SBTN segment can work as follows. SBTN objects ensuring the passage of the maximum flow are sequentially included in the segment, until the resulting network becomes connected, that is, it covers all key transport zones, and between any zones there is a path through the objects of this SBTN segment. To solve this problem, it is possible to use Kruskal's algorithm (an algorithm for finding the minimum spanning tree in a graph), known from graph theory. This approach is practically not used in the domestic literature in relation to the transport industry, except for individual developments in relation to agglomerations [9].

The resulting graph will have the form of a tree (in the terminology of graph theory), i.e., a graph without cycles that covers all vertices of the graph. This graph contains the minimum number of edges that makes it possible to «travel» from any vertex to any other. Thus, the first basic segment of the SBTN is the minimum subgraph of the SBTN, which ensures the connectivity of all transport zones of the territory under consideration, and at the same time the passage of the largest traffic flow. The graph of the first basic SBTN segment can be called the SBTN skeleton or the SBTN core transport structural framework. Spanning tree paths (path along SBTN transport structural framework) may be too long between some transport zones. Therefore, if there are additional reserves of resources for maintenance and repair, it is advisable to supplement the SBTN transport structural framework with SBTN objects, providing them with financing to shorten the paths along the SBTN transport structural framework and provide the ability to lay routes between different branches of the spanning tree.

By adding edges (objects) to the SBTN transport structural framework, the spanning tree turns into a general network with the possibility of using shorter paths between transport zones. Such a network represents the second segment of the SBTN.

The task of constructing the second segment can be formulated as follows. Segment 2 includes all vertices and edges of the first segment, as well as SBTN objects that are not included in segment 1, ensuring the passage of the maximum total flow so that their total financing does not exceed the specified budget constraint. (Required note: since the spanning tree contains all the nodes of the graph, it is possible to add any edges (SBTN objects) to it and the graph will remain connected). Subject to an increase in the funding limit, it is possible to build the next segment of the SBTN, which will include the previous segment and will contain more edges (objects) of the SBTN, which will make the transport network graph even more connected, that is, containing a larger number of valid routes between vertices (transport zones). In this way, it is possible to build several segments, each of which will correspond to the allocation of a certain additional limit for financing activities for maintenance and repair of transport infrastructure facilities.

2. Proposed Algorithms

SBTN facilities are included in the priority subset of facilities (SBTN segment) based on the principle of performing the maximum transported volume per year.

Kruskal's algorithm (modified) for constructing the first segment of the SBTN – the minimum spanning tree or core transport structural framework of the SBTN – works as follows.

Let there be N nodes (vertices) within the SBTN graph. The algorithm starts working with N trees, each of which initially consists of one single vertex – a specific node of the SBTN graph. Next, the edges of the SBTN graph are sequentially added to the trees, connecting different trees. Edges connecting the vertices of one tree are not considered so that the tree does not turn into a network, since the connection of two vertices of the same tree leads to formation of a cycle in the resulting graph, which ceases to be a tree and turns into a network of a general form. When an edge is added connecting two different trees, these trees merge and form one new tree. In this case, the tree with a lower number absorbs the tree with a higher number. At each step, between the trees, an edge with the maximum volume of traffic is found. The process continues until all the trees merge into one single tree, numbered 1. This tree will be the minimum spanning tree that allows flows with the maximum total volume to pass through. In the classical Kruskal's algorithm, traffic volume is not considered.

Modified Kruskal's algorithm for constructing the basic S_1 segment (transport structural framework) of the SBTN

Data: $T_1, \ldots, T_N$ – SBTN spanning trees, each of which initially consists of one vertex (node) of the SBTN graph.

Start: $W = 0$ – initial value of the total volume of traffic of the formed segment S_1.

Cycle 1 of constructing a S_1 segment (infinite loop with exit condition).

Searching for an edge e_{ij} of the network graph, connecting two trees T_i, T_j, where $i < j$, which has a maximum estimate $W(e_{ij})$ of traffic volume.

Attaching the tree T_j and the edge e_{ij} to the tree T_i, that is, to set $T_i = T_i \cup e_{ij} \cup T_j$. Then to set $W = W + W(e_{ij})$.

If the tree T_1 has absorbed all other trees, i.e. only one tree T_1 remains, then exit the cycle 1.

End of cycle 1.

The resulting spanning tree T_1 forms the first basic segment (transport structural framework) of the SBTN i.e. $S_1 = T_1$.

End of the algorithm of construction of the S_1 segment of the SBTN.

As a result of applying the modified Kruskal's algorithm, the SBTN subgraph will be found in the form of a spanning tree for all key transport zones. The constructed subgraph is connected and ensures the passage of flows that together have the maximum volume. This subgraph is the transport structural framework of the SBTN. The construction of the SBTN transport structural framework meets the criterion of network connectivity and the criterion of alternativelessness, since unalternative paths (edges) of the transport network graph that do not have alternatives will automatically be included by Kruskal's algorithm in the minimum spanning tree.

The following S_t segments, where $t = \overline{2, q}$, i.e., segments of the next levels, starting from the second, are built subject to additional funding limits C_t for maintenance and repair of SBTN facilities.

Algorithm for constructing segments of level 2 and subsequent levels

Cycle for construction of segments $t = \overline{2, q}$ (starting from the second).

Construction of the segment with the number t:

Determining the specified financing limit C_t for a given segment t.

If there is no limit, then exit the segment construction cycle.

If there is at least one object o, that has not been included in the constructed SBTN segments, and whose cost of maintenance and repair is less than the specified funding limit C_t^o, then it is necessary to construct the SBTN t segment by solving the optimisation problem of maximising the total volume of transportation of objects o_j of the transport network included in the considered segment, with a given restriction on the funding limit C_t for maintenance and repair of its facilities.

End of Cycle 1.

End of construction of segments.

The construction of the SBTN t segment is carried out by solving an optimisation problem, in which the optimisation criterion expresses the maximisation of the total volume of transportation of objects o_j of the transport network included in the considered SBTN segment:

$$\sum_j x_j \times W(o_j) \rightarrow \max,$$

where,

$W(o_j)$ – traffic volume for an object o_j.

The limitations of the problem express the absence of exceeding a given limit for financing maintenance and repair of objects of the formed SBTN segment:

$$\sum_j x_j \times C(o_j) \leq C_t,$$

where $C(o_j)$ – volume of financing C_t for maintenance and repair of an object o_j;

C_t – limit on financing maintenance and repair of facilities included in t segment of the SBTN.

This optimisation problem has the form of a linear programming knapsack problem, more precisely 0–1 knapsack problem, and is solved by the standard method (dynamic programming). In the case of large dimensions, an approximate, so-called greedy algorithm or other similar algorithms (depending on the problems being solved) can be used for the solution [10].

Approximate algorithm for constructing t segment of SBTN

Let first set $OC_t = C_t$ that is, the remainder of the funding limit OC_t is initially equal to the specified limit C_t.

Segment construction cycle (infinite loop with exit condition).

To find among the SBTN objects of all modes of transport, an object *o* with a maximum volume of traffic $W(o)$, that fits within the given funding limit, i.e., such that $OC_t - C(o) \geq 0$.

To include the found object in the generated segment $S_t = S_t \cup o$, to set $W = W + W(o)$. $OC_t = OC_t - C(o)$.

If an object with the above properties is not found or all edges of the SBTN graph are included in the segment, then it is necessary to finish building the SBTN segment, that is, to exit the segment construction cycle.

End of the segment construction cycle.

The application of the described algorithms will result in construction of SBTN segments forming a connected transport network, including the basic transport structural framework of the SBTN, as well as additional sections of the network that ensure the passage of traffic flows with the largest volume of traffic, which together satisfy the given restriction on financing their maintenance and repair.

It is to note that in the algorithms described above for formation of SBTN segments, it is possible to consider the amount of transport work performed by transport network objects. In this case, for transport network objects, the so-called total freight and passenger transport intensity or normalised freight intensity, calculated as normalised freight and passenger turnover (transport work) per kilometre of travel, is considered. Here the normalised freight turnover is calculated with the formula $P = Pcargo + k \cdot Ppass$, where *Pcargo* is cargo turnover; *Ppass* – passenger turnover; *k* is the coefficient of reduction of passenger turnover to freight turnover (for example, for railways it is taken equal to 1). This calculation option allows us to consider in detail the volume of transportation, including transportation that uses the resources of the considered sections of the transport network not completely, but only partially over a certain length. However, this requires the use of additional initial data and complicates the calculations.

When forming the second and subsequent segments of the SBTN, it is possible, as an additional option, to use the network connectivity criterion, which takes into account the requirements for the presence of direct transport links along the SBTN infrastructure between certain priority transport zones or network nodes, for example, connections between the city of Moscow and the capitals of neighbouring states, or capitals of constituent entities of the Russian Federation with cities with a population of more than 100 thousand people, etc. It should be noted that such transport connections are highly likely to be included in the SBTN by the algorithms described above. This is because a feature of the transport network of the Russian Federation is the absence of a large number of alternative routes of comparable quality between its main nodes, and the most efficient routes between them are the most in demand when transporting goods and passengers, that is, they will be selected into SBTN segments by the algorithms described above. However, when forming the SBTN, if there are additional requirements for the presence of direct transport connections via the SBTN between key nodes of the network, then it is advisable to check the fulfilment of these requirements using the algorithm given below.

The algorithm for including direct transport links into the SBTN or checking their availability is similar to that described above. For each pair of given nodes *A, B,* the shortest path between them is found. As the path length, it is advisable to use an estimate of the cost of transportation between nodes *A* and *B*, that is, consider the most economical path between nodes. For the found path, the total estimate of the cost C(A, B) of maintenance and repair of its sections that were not included in the previously formed SBTN segments is calculated. If all sections of the found path are already available in the SBTN, then the presence of a direct transport connection between nodes *A* and *B* is considered confirmed. Among the considered nodes, direct connections between which are not confirmed by the SBTN, a pair A_i, B_j is found with a minimum estimate of $C(A_i, B_j)$, and if the total cost of maintenance and repair of objects of the formed current segment of the SBTN together with the value $C(A_i, B_j)$ do not exceed the funding limit for objects in this segment, then the edges of the path under consideration that are not included in the already constructed SBTN segments are included in the formed segment. These actions are repeated for the remaining pairs of nodes until the limit of total funding for maintenance and repair of objects selected for the formed segment is reached. Various approaches can be used to visualise a network; this issue was also considered in the works of Russian researchers [11].

Finally, the SBTN will additionally include objects through which the cheapest direct transportation links between specified network nodes pass, or it will be confirmed that such transport links have already been included into the SBTN.

CONCLUSION

As a result of applying the described algorithms, a set of objects (nodes and edges) of the SBTN will be formed that meets the specified criteria.

• The network graph connectivity criteria are satisfied using the developed modified Kruskal's algorithm, which ensures the finding of an SBTN graph connecting all transport zones.

• The quantitative selection criterion is considered in the modified Kruskal's algorithm by finding the edges of the base spanning graph (structural framework) of the SBTN with the maximum volume of traffic, and then by attaching additional edges of the next network segment to the base framework, also with the maximum volume of traffic.

The development of the SBTN using the developed algorithms satisfies the restriction on financing activities for maintenance and repair of infrastructure facilities included into the SBTN.

In the future, development of a connected graph of the SBTN network can be used in formation of a transport and economic balance based on methods developed by Russian researchers [12; 13].

REFERENCES

1. Newman, J. Increasing the ability of government agencies to undertake evidence-informed policymaking. *Evidence Base*, 2020, Iss. 2, pp. 1–9. DOI: 10.21307/eb-2020-005.

2. Kapoguzov, E. A., Chupin, R. I. Possibilities of using an evidence-based approach for analyzing industrial policy [*Vozmozhnosti ispolzovaniya dokazatelnogo podkhoda dlya analiza promyshlennoi politiki*]. *Bulletin of Kemerovo State University. Series: Political, sociological and economic sciences,* 2022, Vol. 7, Iss. 3 (25), pp. 323–330. EDN: UCIUOA.

3. Bychkova, A. A. Investments in the transport infrastructure of Russia [*Investitsii v transportnuyu infrastrukturu Rossii*]. *Vestnik universiteta*, 2022, Iss.2, pp. 151–159. EDN: AUTTNE.

4. Melo, P. C. Transport Infrastructure Effects on Economic Output: The Microeconomic Approach. In: International Encyclopedia of Transportation, Elsevier, 2021, Vol. 1, pp. 347–354. Ed.-in-chief Roger Vickerman. ISBN 978-0-08102-672-4. DOI: https://doi.org/10.1016/B978-0-08-102671-7.10065-X.

5. Popova, Y. Relations between Wellbeing and Transport Infrastructure of the Country. *Procedia Engineering*, 2017, Iss. 178, pp. 579–588. DOI: 10.1016/j.proeng.2017.01.112.

6. Berdnikov, S. V., Patrakeeva, O. Yu. Transport infrastructure and economic growth: the problem of assessing effects [*Transportnaya infrastruktura i ekonomicheskiy rost: problema otsenki effektov*]. *System modelling of socio-economic processes: proceedings of the 42nd International Scientific School-Seminar*, Rostov-on-Don, 01–06 October 2019, Voronezh: Voronezh State University, 2019, pp. 46–51. EDN: BGRKMO.

7. Rosik, P., Wójcik, J. Transport Infrastructure and Regional Development: A Survey of Literature on Wider Economic and Spatial Impacts. *Sustainability*, 2023, Vol. 15, Iss. 1, 548. DOI: https://doi.org/10.3390/su15010548.

8. Krygin, A. A., Kupriyanov, B. V. Determination of critical nodes of the transport network [*Opredelenie kriticheskikh uzlov transportnoi seti*]. *Upravlenie bolshimi sistemami*, 2022, Iss. 100, pp. 194–215. [Electronic resource]: http://www.ubs.mtas.ru/upload/library/UBS10009.pdf. Last accessed 26.12.2023.

9. Makarov, I. N. Efficiency of functioning and development of the transport system of a large city and urban agglomeration: optimization criteria, the need for multimodal interaction [*Effektivnost' funktsionirovaniya i razvitiya transportnoi sistemy krupnogo goroda i gorodskoi aglomeratsii: kriterii optimizatsii, neobkhodimost multimodalnogo vzaimodeistviya*]. *Bulletin of Irkutsk State Technical University*, 2018, Vol. 22, Iss. 1, pp. 209–217. EDN: YMMWJK.

10. Kozlova, M. G., Lukyanenko, V. A., Makarov, O. O., Rudenko, L. I. Specifics of constructing multi-agent routes in hierarchical networks [*Spetsifika postroeniya mnogoagentnykh marshrutov v eirarkhicheskikh setyakh*]. *Tauride Bulletin of Informatics and Mathematics*, 2022, Iss. 2 (55), pp. 7–29. EDN: PICXDW.

11. Gyulling, A. O., Vorontsova, N. V. Visualisation on graphs [*Vizualizatsiya na grafakh*]. *News of Tula State University. Technical science,* 2023, Iss. 2, pp. 128–137. EDN: MLCYDT.

12. Evseev, O.V., Murashov, V.V., Zaboev, A.I. [*et al.*]. Transport and economic balance and its role in coordinating transport planning in the context of digital transformation [*Transportno-ekonomicheskiy balans i ego rol v koordinatsii transportnogo planirovaniya v usloviyakh tsifrovoi transformatsii*]. *Modern information technologies and IT education*, 2018, Vol. 14, Iss. 3, pp. 717–726. EDN: YYHQUH.

13. Efimova, O. V., Baboshin, E. B. Transformation of the methodology for forming the transport and economic balance [*Transfomatsiya metodologii formirovaniya transportno-ekonomicheskogo balansa*]. *Ekonomika zheleznykh dorog*, 2022, Iss. 6, pp. 29–38. [Access restricted to subscribers]. EDN: NEOWRB. ●

Information about the authors:

Karlov, Arthur V., *Junior Researcher of Centre for Strategic Programs of Russian University of Transport, Moscow, Russia, karlov@edu.rut-miit.ru.*

Evseev, Oleg V., *D.Sc. (Eng), Associate Professor, Senior Scientific Officer of the Scientific Centre for Complex Transport Problems of the Ministry of Transport of the Russian Federation, Moscow, Russia, evseev@mintrans.org.*

Article received 30.11.2023, approved 26.12.2023, accepted 29.12.2023.