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Defining Standard of Access to Domestic Air Travel

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ABSTRACT

Transport systems, in particular civil aviation, occupy an important place in development of any modern state. The effective design of such systems has a positive impact on the socio-economic component of any country. The quality of the transport system can be assessed through the population's access to it. At present, one of the important problems of long-term development of the air transport system of the Russian Federation is definition of a universal indicator that allows assessing access to transport and its possible target standard.

The article proposes an approach for assessing access to air travel using mathematical modelling. Two indicators are used as a criterion: a potential number of passengers in the gravitation zones of each airport and a passenger's time being in the system. A methodology for determining the proposed indicators has been developed. The application of the approach of assessment of access to air travel is demonstrated on the 2019 network.

An example of a target (simulated) network of domestic passenger air transportation is also given, which allows to significantly increase access to air travel. Based on the results obtained, the paper proposes target standards for the values of access to air travel for the Russian Federation.

Keywords: air transport system, access to transport, mathematical modelling.

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INTRODUCTION

The socio-economic success of any country directly depends on development and efficiency of its transport systems [1; 2], in particular, of civil aviation. One of the key characteristics of the transport system is availability of access to it [3; 4], and connectiveness [5–7]. There is at least one known attempt by government authorities to set the criteria for availability of transport services in view of long-term development of the transport system. For example, the report [1] states that by 2050, 90 % of citizens of European Union countries should be able to travel door-to-door in no more than four hours. In the form in which the goal of developing the European transport system is formulated, there are three factors: the first principle «from door to door» reflects the so-called holistic approach to the design of transport systems [8]; the second – the target value does not apply to the entire population (about 50 million people will be outside the action of established standards); third – the choice of an absolute temporal value clearly reflects the geographic features of the region. The distance between four capitals in continental Europe farthest from each other (Lisbon, Tallinn, Helsinki, and Athens) does not exceed 3400 km (five hours of flight time).

Unlike other countries, the Russian Federation has not yet developed a single understanding of the criteria for assessing the quality of the transport system, either in an isolated sense – the aviation segment only, or in a general form, including ground sections. Officially approved indicators for the air transport system (ATS),[2] for example, the mobility rates, the number of routes without transfer in Moscow, are important indicators, but they do not clearly define the transport quality of the national network.[3]

At present, the expert community is only discussing approaches to definition of a universal criterion [9–11], which could objectively assess the transport accessibility [12] of ATS and set its target values.

The *objective* of the study is to develop a methodological approach for assessing the access to air travel to determine its target values.

As a single criterion for access to domestic air travel, the author proposes to consider two complementary indicators: *the potential number of passengers and the time of a passenger being in the system*. The first indicator characterises the very possibility of flying to the desired destination: airports at both the initial and final points are accessed and can be reached by road; there are carriers that operate flights to / from the former and latter airport; it is possible to make one or more transfers while travelling. The time indicator describes the ability of ATS to deliver a passenger from one destination to another in a certain time and with no more than a predetermined number of transfers.

Based on *mathematical modelling* [13; 14], using statistical data, a methodology for calculating the proposed indicators of a single access criterion has been developed. An assessment of the access to air travel as for the network in 2019 was obtained. The choice of 2019 is justified by the fact that it most fully reflects the established ATS of the Russian Federation. Next years of 2020–2021 are

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[1] European Commission, Directorate-General for Mobility and Transport, Directorate-General for Research and Innovation, Flightpath 2050: Europe's vision for aviation: maintaining global leadership and serving society's needs, Publications Office. – 2011. [Electronic resource]: https://op.europa.eu/en/publication-detail/-/publication/296a9bd7-fef9–4ae8–82c4-a21ff48be673/language-en. Last accessed 23.04.2023.

[2] Transport strategy of the Russian Federation for the period up to 2030 with a forecast for the period up to 2035. Approved by the Decree of the Government of the Russian Federation, dated 27.11.2021, No. 3363-r. [Electronic resource]: https://mintrans.gov.ru/file/473193. Last accessed 23.04.2023.

[3] Ed. note: Besides those emphasised by the author, the Transport strategy highlights many definitions and indicators of development of the transport system, population mobility, including aviation mobility. Thus, the Transport strategy has defined for the first time such terms as «air mobility», «local air transportation», «backbone network of airdromes (airports) of civil aviation», «regional air transportation», «social standard on transport services provided to citizens», «access to transport», etc. Forecasted results of implementation of the Transport strategy include: «the capital of neighbouring federal entity of the Russian Federation should be accessed in no more than 5 hours», «possibility of travelling within 12 hours between all the cities of the Russian Federation with population over 100 000». Indicators of the achievement of the goals of the Transport strategy comprise «aviation mobility of the inhabitants of remote and difficult-to-access areas» with respective target values, etc.

Pic. 1. Exemplification of a map of access of settlements to airfields and heliports [developed by the author].

characterized regarding ATS by changes associated with external factors, e. g., Covid-19.

An example of modelling the target network for 2035 is offered, which makes it possible to improve the values of indicators of access to transport relative to the level of 2019 and set their possible target standard.

RESULTS

Methodology for Determining Access to Transport

The developed methodological approach to determining access to transport involves two stages. At the first stage, by modelling each airport's coverage area, the potential number of passengers entering the ATS is determined. The «coverage area»[4] refers to the potential number of passengers that can be attributed to a particular airport. The second stage is devoted to the calculation of the time spending per a passenger of a particular airport.

1. *The potential number of passengers* PP_i of the airport $X_i, i = 1,\ldots,N$ is determined as the number of residents (as a share of the total population of the country) who have access to the national air transport system:

$$PP_i = \frac{Z_i}{Pop_{RF}},\ i = 1,\ldots,N, \qquad (1)$$

where Pop_{RF} – population of the Russian Federation;

Z_i – coverage area of the *i-th* airport;

$N \in \mathbb{N}^*$ – set of all airports in Russia.

[4] *Ed. note:* the term used by the author is to some extent beyond the gravity model but is closer to the meaning of areas for the inhabitants of which an airport is within the reach in reasonable time and, with nuances added, can ensure travel to certain point within a specified time, literally meaning an area where passengers can be collected and transported to the airport, thus terms «airport coverage area» either «airport gravitation zone» are used for translation just in the above sense.

The potential number of passengers in general for the ATS of the Russian Federation can be determined as:

$$PP = \sum_{i=1}^{N} PP_i,\ N \in \mathbb{N}^*. \qquad (2)$$

In the general case, the size of population the settlement, next to which the airport is located, does not coincide with its gravitation area. In addition, often there may be several airports near the settlement. Therefore, determining the size of the coverage zones $Z_i, i = 1,\ldots,N$ is singled out as a separate subtask.

To determine the population in the coverage areas, a mathematical model is used [15], in which the time to get to the airport is taken as the main measure of overcoming space. The time of a ride from the settlement to the airfield is determined considering the length of the existing road network. As the upper limit of remoteness of the settlement from the airfield, a great-circle distance of 500 km is assumed. The maximum allowable travel time is limited to five hours. The choice of such a time limit is due to the large extent of the territory of the Russian Federation, as well as to uneven distribution of the population and ground infrastructure facilities. An example is the territory of the Jewish Autonomous District, where there are no airports. The largest and closest airport is Khabarovsk, which is located in another region, while the car trip will take about five hours, which confirms the value of the chosen upper limit.

When modelling, using the weight function [15], alternative airfields located within a radius of 500 km are also considered. The attractiveness of an airfield for a settlement depends on frequency of flights and remoteness, and is expressed in the form of weight coefficients, due to which the population is distributed among the coverage zones of airports.

Pic. 1 shows as an exemplification a fragment of the map developed by the author and referring to the access of settlements (within five hours by road to get to the airport) to flight points. Blue and purple dots indicate airfields and heliports. Green, yellow, orange, and red dots[5] indicate settlements depending on the distance. For red dots, the airport is not reachable or is reachable in more than five hours by road. Points in the immediate vicinity of airfields are marked in green.

Solving the problem of identifying gravitation areas for each of the country's airports allows solving the main problem: to determine the existing or prospective range of values regarding the access to domestic air travel.

2. *Time of a passenger being in the system* TS_i for the airport $X_i, i=1,\ldots,N$ is determined as the maximum value of the minimum times, during which it is possible to fly from the given X_i airport to any X_j , $j=1,\ldots,M$ airport from the set $M \subseteq N-1$ of available airports with at most a given number *k* of transfers on *l* routes:

$$TS_i = \max_{j=1,\ldots,M} \min_{l=1,\ldots,L} T_{ij}^l, \qquad (3)$$

$$i=1,\ldots,N, j=1,\ldots,M, l=1,\ldots,L, \quad N,M,L \in \mathbb{N}^*.$$

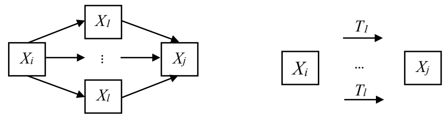
In the formula (3), T_{ij}^l is the time spent on transportation from X_i airport to X_j airport with no more than *k* transfers; *L* is the set of possible routes to reach the airport X_j from the given one. Obviously, for a fixed *k*, there is a probability of getting from X_i to X_j in several ways. The non-uniqueness of the connection is also typical for the direct route ($k=0$), since there may be several flights that differ both in schedule and in flight time (Pic. 2).

Minimisation in (3) provides a search for the best flight time among all routes with different allowable number of transfers for the pair $X_i \rightarrow X_j$. And maximisation allows getting the upper estimate of the transportation time among the best (minimum) for the airport X_i .

The total travel time T_{ij} for one of the possible *l* routes with *k* transfers can be determined as:

$$T_{ij} = \sum_{n=0}^{k} (t_n + \tau_n), \qquad (4)$$

where t_n – flight time on one of the route segments;



Pic. 2. An exemplification of the non-uniqueness of routes from X_i to X_j (it is not a result, but explanatory illustration [compiled by the author].

τ_n – flight waiting time.

In equation (4), if time of a direct flight between any two airports can be obtained from statistical data, for example, the regular schedule of domestic air transportation, then determining the allowable waiting time for a flight τ_n becomes an additional task.

So, the flight waiting time before the flight and route segments can be calculated from the annual frequencies on the lines for X_i airport of departure as the ratio of the number of days in a year to the number of flights performed. Then the flight waiting time for the *i*-th airport can be determined as:

$$\tau_i = \frac{365 \cdot \mathcal{T}}{R_{ij}}. \qquad (5)$$

In (5) $\mathcal{T} = \{0;12;24\}$ – is transit capacity (throughput) factor (total for the system);

R_{ij} – number of flights on a route segment ($k>0$) or a direct line ($k=0$) from X_i to X_j .

The transit capacity coefficient allows getting the waiting time under three aspects: at 0 – there is no waiting time for the flight; at 12 – waiting time equal to the average time; at 24 – the maximum waiting time. In other words, these three aspects correspond: the first to a perfectly synchronised schedule throughout the system (without waiting), the second to partially synchronised (multi-segment flights with a network carrier on most segments); the third is the most unbalanced schedule (commercial connectivity of the network is completely absent).

As an alternative estimate of the flight waiting time, a range of values from 40 to 180 minutes can be used. According to,[6] the lower limit of the transfer window, that is MCT – minimum connection time, is about 30–40 minutes. The upper limit directly depends on the standards

[5] *Ed. note:* coloured version is available on the Website.

[6] a International Air Transport Association (IATA). Minimum Connect Time (MCT) User Guide. [Electronic resource]: https://www.iata.org/contentassets/638f0938b3dd451b872a1d8357755421/minimum-connecting-time-user-guide_version-1.1.pdf. Last accessed 24.04.2023.

Pic. 3. Obtained values of access-to-air-travel indicators for 2019 [the result of modelling of indicators of access to air travel for 2019 obtained by the author].

adopted by each airport and by airlines. For large, modern airports, the average transfer time is about 1–3 hours. However, with this approach, it is necessary to consider the departure time of each flight at each airport based on the regular schedule of passenger air transportation.

In addition to determining the waiting time, an important parameter for calculating the network coverage time indicator is the maximum allowable number of transfers *k*. Modern ticketing systems allow flights with no more than three transfers. However, considering the geographical features of the country, as well as uneven distribution of the population, it is proposed to raise the limit on the number of possible transfers to five.

The search for all T_{ij}^{l} is carried out by forming a set of all possible routes from X_i to other airports within the network. The set of all routes is obtained from the integration of direct routes with routes having one or more transfers. To obtain a route with a transfer, the Cartesian product of direct flights (many-to-many relationship) is used. After that, the following restrictions are imposed on the received routes:

• Correspondence of the airport of arrival to the airport of departure:

$$\{X_i \rightarrow X_j | \; X_i \rightarrow X_n, \; X_m \rightarrow X_j, \; n = m\}. \quad (6)$$

• Exclusion of cycles of one or more segments in the route:

$$\{X_i \rightarrow X_j | \; X_i \neq X_j\}. \quad (7)$$

Routes, flights along which do not meet the specified criteria, are not considered. Two airports for which no route matching the criteria was found are considered unreachable. To obtain routes with more than one transfer, an increase in the number of Cartesian products of direct flights is used, considering restrictions (6), (7) for each new shoulder. To the final set of all flights containing routes with $k = 0, 1, \ldots, 5$ transfers, a selection is applied that allows getting the best (minimum time to each X_j) flights for each X_i. Also, for each departure point, the population located in the gravitation area is put in correspondence with the potential number of passengers (PP_i). Next, the choice of the maximum time spent on transportation among the points of departure, providing a certain proportion of the population of Russia.

Unlike PP, TS or «ability» to reach the destination point does not have a well-defined range of values. First, because it cannot be considered in isolation from the geographical characteristics of the country and the peculiarities of the population distribution across its territory. The great-cycle distance between the two most remote airports (Simferopol and Mendeleevo (Kunashir Island)) is 8067 kilometers. With an average jet aircraft cruise speed of 800 km/h, the travel time between these two points, considering the actual route, will be at least 12 hours. This value sets a certain benchmark for the minimum theoretical value of *TS* for 100 % of the citizens of the Russian Federation.

Assessment of Access to Domestic Air Travel in 2019

To determine the range of realistic values for access indicators to domestic air travel, diagnostics of its already achieved parameters were carried out. ATS of 2019 was chosen as the basic transport system for calculating access indicators. The number of transfers available was limited to five. Flight waiting time is determined based on average annual frequencies ($\mathcal{T}$ =12). On the graph (Pic. 3), the author presents the result of calculations of the proposed access indicators: a graph of the dependence of *PP* on *TS* for the entire ATS.

The simulation results showed that, under given boundary conditions, there is no airport that would be connected to all other airports in the country.

As can be seen from the graph, half of the country's population is eight hours apart from each other when travelling only by air (excluding the ground segment). Then there is a rapid increase in network connectiveness: with an increase in the time spent by a passenger on a journey by 20 % (up to 10 hours), the share of the population connected by air transport grows by more than 40 %. Then the potential to gather and transport passengers in a relatively compact and densely populated part of the country is exhausted, and the shortcomings of the existing ATS begin to manifest themselves in the most obvious way. Less than 3/4 of Russian citizens live within the previously stated benchmark of 12–15 hours. At the same time, more than 19 million people (13 %) live at more than 24 hours from the rest of the country.

Possibilities to increase access rate are concentrated in two directions. First, the shift of the distribution curve to the left, that is, a reduction in the time indicator of coverage, and upwards – an increase in the share of the population with a fixed time for provision of transport services.

Assessment of Access to Domestic Air Travel in 2035

Along with the assessment of the access to ATS in 2019, application of the proposed indicators of the access was considered for the target (simulated) route network for 2035. Modelling of the domestic air transportation network is based on the number of connections a particular airport has with other airports in the country. The main criterion for the quality of the total route network is to ensure the minimum travel time for the largest possible share of the country's population.

The target air transport system is proposed to be considered as a three-rank graph. Airports of the first rank form a backbone network and have connections with each other following the principle of «each with each». This segment includes 12 airports (Moscow, St. Petersburg, Yekaterinburg, Krasnodar, Novosibirsk, Omsk, Krasnoyarsk, Yakutsk, Samara, Rostov-on-Don, Irkutsk, Khabarovsk), which account for a larger passenger flow, as between the airports of the core network, as well as for transit flows from other segments of ATS.

The set of the second rank includes 133 airports connected with nodes of the 1st rank, partially with each other and with airports of the 3rd rank. This group is a fundamentally important segment that ensures the speed of transit throughout the entire network.

The remaining points of the route network make up a group of the 3rd rank, which are connected only with airports of the second rank and do not have a direct connection with the route network of the first rank. The airports of this segment are «dead end» destinations and close (open) only the last (first) shoulder in the country's route network. This segment of the ATS is characterised by 247 airfields and landing sites. The ranking of airports and airfields was developed also in the form of the map, an exemplification is shown in Pic. 4.

The proposed reorganisation of the air transport network implies a transition to a «hub» system, that is, a reduction in operation of direct lines in favour of flights with transfers. This approach renounces to operation of non-stop lines with low traffic, at the same time new air links are being formed on routes where there is currently no direct air service, but there is enough potential passenger traffic for a daily flight.

The assessment of potential passenger traffic between cities is determined using multiple regression [16]. The list of influencing factors included the income rate and the population at the points of departure and arrival those factors being standard for such traffic generation models.

When modelling the network and redistributing flows, the following assumptions were taken:

• Operation of the route necessarily implies implementation of at least 300 flights per year.

• Operation of the route begins with an aircraft with the minimum available passenger capacity (19 seats for routes up to 800 km long).

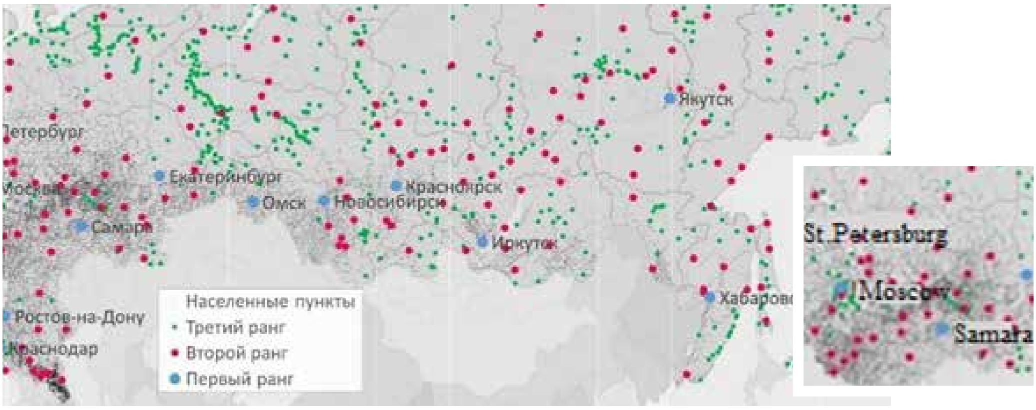
• When the planned level of the aircraft's load factor is reached, the second flight starts to be operated instead of changing aircraft for increasing passenger capacity.

• Replacement of an aircraft for a larger one is carried out with an increase in passenger traffic to the level of full booking of two flights per day.

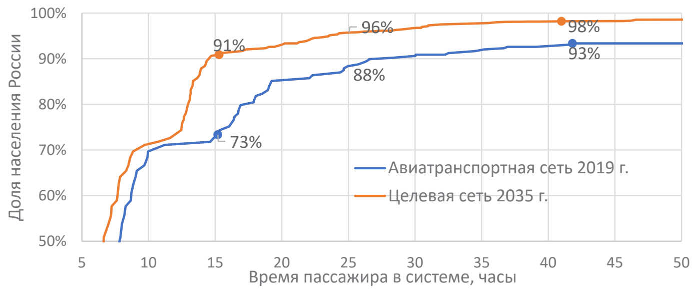
• Maximum calculated frequency on the route is no more than four daily flights.

• Routes from the 3rd rank airports terminate at the 2nd rank airports; to increase the commercial load, up to two intermediate landings are allowed.

• Connections between two airports of the 2nd rank located in the area of the same hub (up to



Pic. 4. The territorial location of the airports and airfields by rank [developed by the author].



Pic. 5. Actual and target values of indicators of access to air transport system of the Russian Federation [final result is obtained and performed by the author].

1000 km) are organised with a connection in the hub if the passenger flow on them is insufficient for a direct flight.

• Increase in the length of the route should not exceed 50 %.

• Connections between airports of the 2nd and the 1st ranks that existed in the first year of modelling are preserved for the entire period.

Because of changes in the structure of the air transport system, values of indicators of access to domestic air travel have been significantly increased (Pic. 5). Even though it was not possible to achieve full connectivity of the entire network, the number of Russian citizens who will not have access to all airports in the country without exception will decrease. If at present, with rather mild restrictions on the quality of the flight, 10 million people have no access to the entire airport network, then formation of a latitudinal chain of hubs and concentration of regional traffic in them will reduce this indicator by more than three times.

Even more significant improvements can be awaited in the segment of not extremely long and complex air links. For 50 % of the population, the travel time to each other will be reduced by almost 1 hour and 20 minutes, and for 91 %, instead of today's 73 %, the time spent on board the aircraft and waiting at airports will not exceed 15 hours in total.

Based on the obtained results of the air transport system modelling, the target standards for access to domestic air travel can be set within the following limits:

7 hours $\le (PP = 90\%) \le$ 15 hours.

Setting of the lower limit of *TS* is intended to stimulate the development of the air transport system in the western part of the country. Achieving this indicator will mean a reduction in travel time by almost 15 % for half of the country's population. Setting and meeting the upper *TS* target will result in 25 million more people than currently who will get access to transportation services within 15 hours.

BRIEF CONCLUSIONS

The paper presents a methodology for assessing the access to domestic air travel, based on two criteria: the potential number of passengers and the time of a passenger being in the system. Using the proposed approach, an assessment of access to air transport network of 2019 and 2035 was obtained. The results showed that in 2019 for 50 % of the population of the country, the time for obtaining a transport service (passenger time being in the system) was within eight hours; for 75 % of the population the time increased to 16 hours, and for 90 % the upper limit was of 28 hours. To improve the quality of access to transport and to determine its target values, modelling of the target air transport system for 2035 was carried out. A three-rank network model was proposed. An assessment of the access to domestic air travel in the simulated network showed that for 50 % of the population, the time in the system can be reduced to 7 hours, and for 90 %, the time in the system will be cut to 15 hours, which improves the assessment of the network in 2019 almost by twice. The obtained values of indicators can be considered within the simulated model as target access standards.

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