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Indicator for Assessing Availability of Rolling Stock for Public Urban Passenger Transport

Iosif V. SPIRIN **Yulia M. GRISHAEVA** **Olga Yu. MATANTSEVA**

Spirin, Iosif V., *JSC Scientific Research Institute of Road Transport (JSC NIIAT), Moscow, Russia.*
Grishaeva, Yulia M., *JSC Scientific Research Institute of Road Transport (JSC NIIAT), Moscow, Russia.*
Matantseva, Olga Yu., *JSC Scientific Research Institute of Road Transport (JSC NIIAT), Moscow Automobile and Road Construction State Technical University (MADI), Moscow, Russia*.*

ABSTRACT

The objective of the article is to develop and to substantiate adequacy of the proposed indicator for assessing availability of rolling stock for urban mass transit or urban passenger transport (UPT). As such an indicator, it is recommended to use a calculated indicator: a conventional one-hundred-seat vehicle. The currently used indicators characterising provision of UPT with vehicles, consider only the physical number of the latter. This does not provide an assessment of carrying capacity of UPT, considering the existing operating conditions (real operating speeds on the routes of UPT, the existing level of the coefficient of the fleet being used on the routes as compared to the total number of fleet units, etc.). The proposed indicator of availability of the rolling stock considers not only the natural number of vehicles, but also their passenger capacity, the indicated significant technical and operational indicators of the vehicle fleet. The basis for assessing the carrying capacity of the rolling stock fleet is a conventional one-hundred-seat bus, which performs transportation on routes with an average operating speed. For real buses, this basic unit is adjusted in accordance with real travel speeds and the prevailing values of technical and operational indicators. A similar adjustment is performed for real trolleybuses and tram cars, which makes it possible to level the operational differences in the rolling stock of various types of UPT to compare them in terms of carrying capacity.

The methodology used in preparation of the article is based on the integrated use of scientific knowledge in the fields of applied science on operation of transport, statistics (statistical observation and accounting of the work of UPT), a comparative analysis of indicators used in various industries, in particular, in agriculture to assess the level of provision with the main production vehicles (conventional tractor), benchmarking research and development of Russian and foreign authors on the problem of improving operation of UPT.

The indicator is intended for use in development and assessment of the level of implementation of programs for development of UPT and the urban environment, analysis of the quality of transport planning and services provided to passengers, comparisons of provision with vehicles in different cities.

Keywords: *urban passenger transport, indicator, vehicles, population security, transportation planning.*

*Information about the authors:
Spirin, Iosif V. – D.Sc. (Eng), Professor, Senior Researcher of JSC Scientific Research Institute of Motor Transport (JSC NIIAT), Moscow, Russia, ivspirin@yandex.ru.
Grishaeva, Yulia M. – D.Sc. (Pedagogics), Associate Professor, Head of Ph.D. Studies Department of JSC Scientific Research Institute of Motor Transport (JSC NIIAT), Moscow, Russia, j.m.g@mail.ru.
Matantseva, Olga Yu. – D.Sc. (Economics), Ph.D. (Eng), Deputy General Director of JSC Scientific Research Institute of Motor Transport (JSC NIIAT) for scientific work, Professor at Moscow Automobile and Road Construction State Technical University (MADI), Moscow, Russia, omat@niiat.ru.

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Background. In Russia, the largest number of passengers are transported by public transport (PT) in cities and their suburban areas. According to the website of the Ministry of Transport of Russia, in 2018, 46,3 % of the total number of passengers in urban traffic were transported by buses, 11,4 % of passengers were transported equally, by trams and trolleybuses, 30,6 % by metro (the rest were transported by taxi). The state and municipal authorities carry out measures to support PT and ensure its sustainable development [1–3].

Rationalization of the composition of vehicles of urban passenger transport (UPT) is of particular importance in the context of implementation of the concept of sustainable development of socio-economic relations. Sustainable development means a balanced approach to solving a set of economic, social, and environmental problems. Public urban passenger transport is of particular importance for ensuring sustainable urban development. Therefore, UPT became a pioneer in sustainable development [1; 3].

A proper accounting of carrying capacity of the rolling stock fleet of UPT is necessary when developing and evaluating implementation of transport development programs, organizing passenger transportation, determining the necessary budgetary funding for urban transport and when establishing the quality level of transport services for the population of cities [4–8].

To carry out these accounting functions, an indicator of the level of provision of the urban population with the rolling stock of UPT is required. Determination of the value of this indicator should be based on the available statistical observation data and should not cause methodological difficulties in calculations. An indicator should be used so that to make it possible to determine availability of rolling stock both separately by the types of UPT, and to establish an aggregate (integral) assessment of its availability in the city. The indicator should also have a «physical meaning», which will provide clarity of its use.

Currently, the state statistical monitoring in Russia provides for registration of the number of rolling stock units of various types of public transport in physical terms. Transport organisations also consider and accumulate data on the planned and achieved values of technical and operational indicators (TOI) of rolling stock and TOI of routes for regular passenger transportation.

The *objective* of the article is to substantiate the indicator of provision of urban population with the rolling stock of public urban passenger transport, considering, in addition to availability of vehicles, their passenger capacity and operating conditions on the routes.

The *methodology* used in preparing the article includes a knowledge and methods from the following fields:

• Applied science in the field of operation of transport systems and road transport.

• Statistical data and departmental accounting of services provided by UPT.

• Practical application of indicators to assess supply of production assets. In particular – the concept of «conventional tractor» used in agricultural sector.

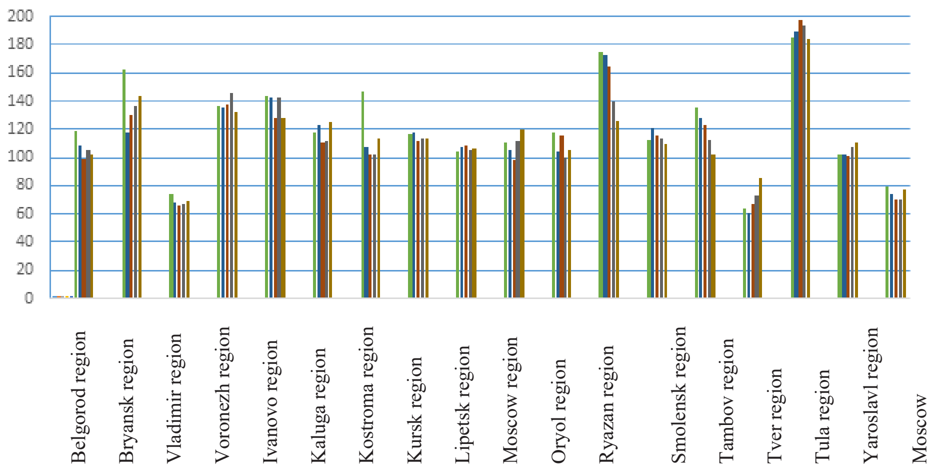
• The results of analysis of publications by Russian and foreign authors, considering approaches to determining the qualitative requirements with regard to rolling stock fleet of UPT, and establishing reasonable indicators for assessing availability of production facilities in performance of work and provision of services.

Developments in the field of determining the provision of UPT with vehicles

The study of scientific and technical literature (about 250 sources) has shown that determination of the required level of provision of UPT with rolling stock is carried out using the following two approaches.

The first one is based on identification of the required number of vehicles for each of the routes, followed by aggregation of the results obtained for the route system of the settlement («bottom-up» calculation). The use of this approach does not allow levelling the influence of exogenous (external) factors of organisation of transportation, since for each of the routes the number of rolling stock units is determined based on the current configuration of the road network, traffic conditions on it and the concept (model), based on which the route system of UPT of the settlement under consideration is formed [5, pp. 165–185]. This approach is used for current determination of the need for vehicles and organisation of transportation on the routes of UPT (in other words, in the present time).

Second approach is associated with the setting of an average standard for provision of



Pic. 1. Provision of public transport buses to the territorial entities of the Central Federal District of the Russian Federation according to Rosstat [Federal State Statistics Service] data: the ordinate indicates the number of buses per 100 thousand inhabitants, units; vertical bars show end-of-year availability in 2015–2019.

rolling stock to the territory of a settlement or its population for the purpose of subsequent use in development of promising projects to improve transport systems of cities, including projects based on the concept of sustainable development. This approach can also be applied to make comparative assessments of urban transport development. The scope of this approach regards future periods of operation of urban transport systems (planning of transport activities). So, in the monograph [5, pp. 144–145] the methodology of the minimum permissible normative provision of the urban area with buses, depending on the average distance of the passenger's trip, is considered.

The article [9] presents an analytical review of publications in the field of the institutional economics of UPT, which suggests the study of passenger transportation by public transport, considering the «external environment»: problems not only at the level of microeconomics of transport organisations, but also intracity policy, a complex of social relations, external results of transport activities, etc. This approach will lead to significant changes in the conditions under which UPT will work in the future. The issues of considering the external consequences of the operation of urban transport were also raised by us in [1].

In the long term, introduction of the provisions of the concept of a smart city into practices of transport planning and operation of UPT will change the approaches to regulation of the provision of cities with rolling stock of public transport. Tools and devices of transport telematics and satellite navigation will provide the possibility to promptly trace the city routes and to provide them with necessary rolling stock. However, transportation on such routes will be carried out mainly by buses and small electric buses. Routes with powerful passenger traffic will be operated using the well-established transportation technology [1; 10]. To determine the need for operational routes in rolling stock, it is necessary to be able to predict passenger flows in the short term. Currently, research in this direction is carried out by Chinese scientists [11].

Statistical data of the Federal State Statistics Service [Rosstat] and the Ministry of Transport of Russia on provision of public buses (see example in Pic. 1)[1] and vehicles of other types of UPT show significant variations over the years of observation and significant differences between the constituent entities of the Russian Federation.

Such changes are explained by uneven economic and social development of the constituent entities, the differences in the proportion of the urban and rural population within their territories, participation of other types and modes of transport in passenger transportation, the size of the territories, the structure of the road and street network, the number and population

[1] Similar examples can be cited for other types of passenger transport and for other federal districts and territorial entities of the Russian Federation.

of settlements within the territories of the constituent entities, changes in the dynamics of traffic, in the fleet of vehicles (acquisition and decommissioning), the structure of the use of vehicles by type of routes, and by other reasons. This confirms the need to use the acquisition and decommissioning of rolling stock, considering the significant factors that cause such differences.

Factors affecting the provision of UPT with rolling stock

Statistical observation accumulates information on availability of rolling stock in natural units of vehicles used (buses, trolleybuses, cars). At the same time, it is not considered that, depending on the model and series of rolling stock fleet, each of its units has a certain passenger capacity. Passenger capacity has a significant impact on the carrying capacity of a vehicle.

The carrying capacity of buses, trolleybuses and trams is significantly limited by the technical and operational indicators of the use of the rolling stock fleet, first, by operational speed V_o of movement on regular routes. For average operating conditions, this speed is approximately equal to:

- for buses – 18 km/h;
- for trolleybuses – 17 km/h;
- for tram cars – 16 km/h;
- for metro trains – 36 km/h;
- for buses of especially small passenger capacity, operated in the route taxi mode – 23 km/h.

An increase in operational speed of movement on the routes of UPT allows an increase in the number of trips during comparable time. In turn, this leads to an increase in carrying capacity of public transport and to a reduction in the time spent by passengers on travel [5; 8]. When calculating availability of rolling stock for a certain city, it is necessary to consider not the indicated average values of operational speed of traffic but to use actual data on operation of UPT in this city.

Carrying capacity of the vehicles used is also influenced by:

- *Average route length*. The shorter is the route, the greater share of the turnaround trip time on it is spent on delays at the final stopping points associated with the turnover of rolling stock (performing technologically determined operations at the final point of the route, a short rest for the driver, transferring the vehicle to the opposite direction of movement). However, there is no need to separately take into account the effect of the route length on carrying capacity of vehicles, since delays at final stopping points have actually already been taken into account when standardising operating speed on each route, for each trip.

• Coefficient of non-straightness of the route (routes). It is obvious that movement of a vehicle in space along a non-straight route from the initial to the final stopping point is slower in comparison with a straightened route.

Obviously, transport organisations of UPT do not have significant opportunities for unhindered straightening of sections of the route system, the outline of which is closely related to the structure of the city's street and road network.

Of course, it is impossible to achieve complete straightness of all routes. In this regard, according to our research, the increased non-straightness of routes leads to overspending of at least 10...15 % of resources, primarily regarding the leading items of the cost of transportation. First, these are the costs associated with vehicle mileage, namely:

• With fuel and electricity consumed by vehicles.

• With wages of vehicle drivers.

• With maintenance and current repair of vehicles.

Considering the foregoing, it is relevant to introduce an indicator into research, which will consider the indicated factors affecting the performance of rolling stock on the routes of regular passenger transportation. Such an indicator can serve as an adequate indicator of the level of provision of the urban population with rolling stock.

The use of the indicator will make it possible to assess and compare the levels of provision of UPT with vehicles in various cities, to determine the priority of financing development of the rolling stock fleet, to carry out a set of measures for organising transportation, that in Russia should be in conformity with the Federal Law «On Organisation of Regular Transportation of Passengers and Luggage by Motor Transport and Urban Land Electric Transport in the Russian Federation and on Amendments to Certain Legislative Acts of the Russian Federation» dated July 13, 2015 No. 220-FZ (as amended), hereinafter referred to also as FZ No. 220, Social standard of transport services for the population when transporting passengers and luggage by road and city electric transport (order of the Ministry of Transport of the Russian Federation dated January 31, 2017 No. NA-19-r), hereinafter referred to also as the Social Standard, other industry standards and building rules[2].

It is proposed to legitimise the indicator under consideration for practical use by including it in the standards of transport services for the population, developed based on a scientifically grounded methodology [12].

Analogue of the vehicle availability indicator

The study of the experience of using indicators of provision with basic production equipment in various sectors of the national economy made it possible to establish the closest analogue for assessing the level of provision of UPT with rolling stock. Such an analogue is the conventional (reference) tractor used in agricultural production – RT.

RT is a tractor, providing the processing of one conditional hectare of land for 1 hour of shift time. At the same time, a plot of arable land corresponding to the area with certain average characteristics is taken as a reference hectare. Those features comprise soil resistivity, ploughing depth, relief (even), rectangular configuration, rutting length per pass through the plot, height above sea level, soil background (presence of stubble of grain crops combined with a certain soil moisture), the absence of stony and other obstacles in the soil.

Thus, the use of the reference hectare in the calculations considers the average operating conditions of RT. The development of the latter is taken as the basis for converting the natural number of tractors into conventional reference tractors. DT-75 or T-74 tractors were previously considered as RT.

Currently, the Ministry of Agriculture of the Russian Federation has recommended[3] for consideration TE-100 (close in parameters to DT-75D tractor), TE-150 (close in parameters to T-150-05-09 tractor) tractors [13].

By analogy with RT, it is proposed to use a conditional (reference) vehicle (RV) as an

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[2] For example, SP 42.13330.2011. Urban planning. Planning and development of urban and rural settlements. Updated edition of SNiP 2.07.01-89 (as amended). Put into effect from 20.05.2011. Moscow: Ministry of Regional Development of Russia, 2011, 109 p.

[3] Method of using conditional coefficients for converting tractors, grain and forage harvesters into reference units in determining the standards for their needs: instructive and methodological edition. Moscow, FGNU Rosinformagrotech, 2009, 56 p.

Table 1

An example of calculating the number of reference 100-seat vehicles (the data are averaged; when calculating in real situations, the actual values should be used) (compiled by the authors)

UPT type	Data on rolling stock				V_o, km/h	Number of reference vehicles, un.
	A_{ll}, un.	α_v	A_{oper}, un.	q, pass.		
Bus	133	0,83	110,39	45	18	49,68
	72	0,79	56,88	76		42,23
	51	0,91	46,41	92		42,70
	23	0,85	19,55	120		24,46
	50	0,93	46,50	11	23	6,54
Trolleybus	44	0,86	37,84	90	17	32,16
	16	0,83	13,28	120		15,05
Tram	66	0,79	52,14	60	16	27,81
	49	0,85	41,65	80		29,62
Total	504	–	–	–	–	270,25

indicator of availability of UPT rolling stock for urban residents. Considering that buses make up the largest share of UPT rolling stock, it is recommended to take a bus with a capacity of 100 passengers, a conventional (reference) one-hundred-seat bus, as RV. At the same time, the one-hundred-seat equivalent is used solely for the convenience of performing calculations according to the proposed method. For the convenience of further presentation, we will introduce the designation of a conventional vehicle (RV_{100}) and an equivalent conventional 100-seat bus RB_{100}. $RV_{100} = RB_{100}$.

Let us assume that operation of RV_{100} on routes is considered under reference (normal, average) operating conditions. Under these conditions, the average operating speed of a route bus is $V_o = 18$ km/h.

The rolling stock of urban land electric transport has different average operating speeds: for trolleybuses, V_o is 17 km/h, and for tram coaches – 16 km/h. Taking this circumstance into account, let us introduce into consideration the conventional one-hundred-seat trolleybus (RTB_{100}) and the tram car (RTW_{100}).

Using the introduced designations, considering the average operating conditions of UPT rolling stock, we obtain the following dependencies:

$RTB_{100} = RV_{100} \cdot 17:18 = 0,944\ RV_{100}$; $RV_{100} = 1,059\ RTB_{100}$;

$RTW_{100} = RV_{100} \cdot 16:18 = 0,888\ RV_{100}$; $RV_{100} = 1,126\ RTW_{100}$.

Since $RB_{100} = 1,059\ RTB_{100} = 1,126\ RTW_{100}$ we get:

$RTB_{100} = 1,063\ RTW_{100}$ and $RTW_{100} = 0,94\ RTB_{100}$.

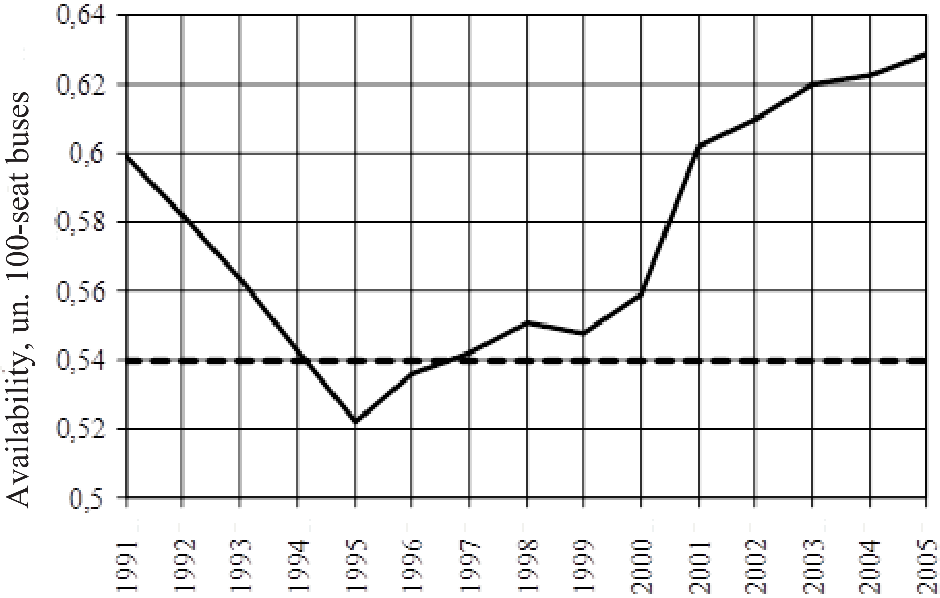
The obtained dependencies are valid for the average operating conditions of vehicles. For real operating conditions in a certain city, the indicated speeds should be adjusted in accordance with the prevailing circumstances.

Reducing natural number of vehicles to a hundred-seat vehicle

When determining the level of provision, running units of rolling stock (A_{oper}) used to work on regular transport routes should be considered and not the average listed rolling stock units that are listed on the balance sheet of transport organisations or leased by them (A_{ll}). The number of running units is equal to the product of A_{ll} and the dimensionless coefficient of output per line (α_v), currently formed or calculated for the foreseeable future (depending on the purposes of use).

Each physical bus, trolleybus or coach corresponds to A_{calc} (calculated RV_{100}), considering the correction factor, which is numerically equal to the ratio of the passenger capacity of the driven rolling stock unit to the calculated reference unit with a capacity of 100 passengers. For example, a bus with a passenger capacity of 63 passengers is equivalent to 63/100 = 0,63 RV_{100}, and a trolleybus with a passenger capacity of 113 passengers is equivalent to 113/100 = 1,13 RV_{100}.

In addition to the passenger capacity, operating speed must also be considered. As a result, it is proposed to use the following dependence to determine the number of conditional 100-seat vehicles A_{calc}:



Pic. 2. Critical level and dynamics of provision with reference buses during the period of the greatest decline in quality of transport services at UPT (compiled by the authors).

$$A_{calc} = \frac{A_{ll} \bullet \alpha_v \bullet q \bullet V_o}{1800}, \qquad (1)$$

where q – passenger capacity of one vehicle, passengers;

1800 – conversion factor obtained by multiplying the passenger capacity of a conventional vehicle (100 passengers) by the average operating speed of the base vehicle – a bus, i.e. 18 km/h, and having the dimension [pass. • km/h].

An example of determining the number of RV is presented in Table 1.

As can be seen from this table, the number of listed RV is 46 % less than the number of average listed vehicles. From the considered example, it follows that the use of only the average number of vehicles in the assessment of availability of rolling stock can introduce an unacceptably large error in the results obtained.

Thus, the main distinguishing feature of the proposed methodology from the known approaches to determining availability of rolling stock is accounting for performance of vehicles, and not only its availability in organisations of UPT, calculated in natural units. The considered indicator reflects the presence of rolling stock, considering the different passenger capacity of the operated vehicles of UPT, operating speed on the routes, and other technical and operational indicators that determine the actual results of operation of the rolling stock. Therefore, the use of the proposed indicator will contribute to an adequate comparison and assessment of carrying capacity of the vehicle fleet and rationalisation of the costs of its renewal and development.

Let us also pay attention to the fact that the proposed method for determining availability of rolling stock is based on the use of available accounting and statistical information in the calculations.

Adjustment of the size of the contingent of passengers of UPT when calculating availability of rolling stock

To standardise the minimum provision of UPT with rolling stock, it is necessary to determine the critical level of the value of this indicator. Let us emphasise that the critical level does not correspond to the minimum value of the provision set by the transport service standards. The critical level can be significantly less than the standardised value, and is established based on the capacity of passenger transportation with the predominant role of public transport vehicles in implementation of public transportation. To ensure this possibility, it seems reasonable to require the fulfilment of at least 50 % of all passenger transportation with UPT. Otherwise, UPT will have an auxiliary value in urban transportation.

An experimental study of 1991–2005 on the temporal dynamics of provision of Russian cities with calculated 100-seat buses (Pic. 2) in comparison with the experimentally established transport mobility of the urban population, showed that the critical value of the level of this provision per thousand inhabitants is approximately 0,54 calculated buses. In 1994–1997 quality of transport services was considerably lower, since the level of provision was below the specified critical value [5, p. 145]. Thus, the hypothetically proposed critical level of 0,54 units was confirmed by the crisis of transport services that occurred during the specified period.

In recent years, the provision of UPT with vehicles, despite a slight reduction in the rolling stock fleet, has improved. The growing motorisation of the population, regarding which the potential contingent of passengers of UPT tends to decline, has a significant impact on this phenomenon.

The coefficient of provision of cities with rolling stock for general use is the ratio of the physical number of UTS units listed on the balance sheets of the city's transport organisations to the standard number of such vehicles. The determination of this coefficient is carried out according to the methodology considered in this article.

Considering that motorisation «pulls over» a part of potential passengers of UPT, when calculating the provision, one should not proceed from the total population of certain cities but make an allowance for the corresponding reduction in the number of users of UPT services. As a first approximation, it is recommended to use the following relationship to determine the size of the contingent of potential UPT passengers (N_{UPT}):

$$N\mathrm{upt} = 0,8\frac{N \cdot A_{1997}}{A}, \qquad (2)$$

where 0,8 – an empirical coefficient that takes into account the completeness of the use of the car fleet owned by residents of the city;

N – population of the city (population size) at the end of the year preceding the estimated period, thousand people;

A_{1997} – the number of passenger car fleet owned by residents of the city at the end of 1997, units. The specified year was chosen for Russia as the basis for comparison since in 1997, according to Pic. 2, the provision of UPT with vehicles was minimal;

A – the number of passenger car fleet owned by residents of the city at the end of the year preceding the estimated period, units.

When calculating availability of rolling stock for certain cities, it is also necessary to consider not only their permanent population, but also the additional daytime population (people who come to work or study from the suburban area).

Note that formula (2) gives a result that is only the first approximation to the true value of N_{upt}, and additional studies are required to obtain a more accurate result.

Conclusion. The methodology for assessing and rationing the provision of UPT with rolling stock, considered in the article, and accounting the real operating conditions of its use, allows to justify projects for development of a fleet of vehicles of UPT for general use, to establish an objectively necessary limit of funds allocated to finance the activities of public transport, to compare the results of operation of various types of UPT vehicles for passenger transportation (considering the costs inherent in these types of transport and productivity of using a vehicle on a route).

While the calculations were executed based on regulations, standards, and statistical data for the conditions prevailing in Russian Federation, the suggested methodology can be adapted to the conditions of other countries and cities.

The outlined approach to construction of the indicator of availability of UPT rolling stock can be supplemented by adjustments to its normative value, considering other factors (e.g., adjustment of the number of passengers in the article is a special case of such actions). Also, by analogy, it is possible to develop indicators of availability of rolling stock for other types of transport and cargo transportation.

Practical use of RV indicator as an indicator of provision of cities with the rolling stock of public transport is possible in the following situations:

- development of projects for development of transport systems of cities, projects for expanding the rolling stock fleet of UPT;

• comparison of real carrying capacity of vehicles of various types of UPT, e.g., when organising various forms of services regarding given mass transit routes (stop-off, express, semi-express, high-speed traffic);

• assessment and analysis of the current situation in provision of cities with rolling stock;

• providing calculations for sustainable development of the urban environment and transport infrastructure, e.g., to ensure compliance with the requirements of the current social standard and building rules.

It should be noted that the design of sustainable transport systems puts forward increased requirements for staffing regarding both designers and operators.

In this regard, it seems necessary to modernise vocational education and improve the qualifications of transport personnel. The main recommendations for solving this problem are set out in the works [14; 15].

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