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METHODS FOR DETERMINING THE NEED TO USE THE METRO IN TRANSPORT SYSTEMS OF BIG CITIES BY MATHEMATICAL SIMULATION

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Abstract
This paper provides the results of the experiment carried out on the transport system of Krasnodar for three settlement periods - 2007, 2017, 2022 years. The experiment was carried out on using the passenger flow model based on the iterative process of changing passenger traffic and speeds in a conditional transport network. The model assumes determining the need for high-speed public transport, in particular, the subway and designing of potential high-speed routes in accordance with passenger flow.

Keywords: city's transport system, transport management, public transport, modeling, transport flow, passenger transport correspondence, passenger flow.

INTRODUCTION

Over the past 100 years, the world has been experiencing rapid urbanization [1] Since the beginning of 2007, more than half of the world's population have been living in cities. According to the UN report on the prospects of urbanization, by 2050, about 70% of the inhabitants of our planet will live in cities. This creates new challenges for urban planning. According to World Bank data, cities generate 80% of the global GDP and are centres of economic and social consumption, however, at the same time they account for 70% of the global CO_2 emission and more than 60% of resource consumption.

A modern city is an extremely complex self-developing organism which sustainable development based on the transport system. As cities are developing, the interaction between the individual components of their transport systems is becoming more complicated. Therefore, in modern transport planning, a vital place is occupied by the issue of determining the most rational distribution of transport modes under the conditions of a unified city's transport system. The indicators of such a distribution can be the share of passenger traffic (passenger work) by types of urban passenger transport (UPT) or the volume of capital investments and operating costs. The choice of the transport types nomenclature for a particular city or agglomeration is not always obvious: cities of comparable building area and population, for various reasons, such historical ones, etc. can focus on different means of transport. For instance, priorities in the development of the subway, light rail or urban rail may represent competing directions in the development of the city's transport system. The issue of choosing transport means is topicality for cities reaching sizes, when it is impossible to use only street ground vehicles (tram, trolleybus, bus). In such a case, it is necessary to select a priority mode(s) of transport, that influences creation of city's transport systems for the following decades. As a rule, the relevance of such a significant choice increases considerably with the population, about 1–1.5 million people. This article provides a description of the developed and tested model, focused on substantiating the choice of the subway as a structure-forming type of urban public transport as a solution of current issue. It is well known that the construction of the subway in large cities and megalopolises leads to an increase in the speed of movement and an increase in the level of transport accessibility of the territory. The subway is characterized by high capacity, environmental friendliness and safety. Meanwhile, the development of the subway is associated with a high level of capital and operating costs, as well as long construction periods.

In the newly designed city, the main factors determining the choice of the nomenclature of (UPT) types and the ratio of their shares are:

• a size of maximum and minimum hourly passenger flows;
• an average travel distance;
• a volume of one-time investments.

In the transport planning practice in relation to already existing cities, as a rule, it means improving the already established structure of transportation by types of UPT, take into consideration the available capacities of transport enterprises, the availability and cheapness of electricity, climate features, etc. The traditional preferences of the inhabitants of a particular city also play an important role [3].

The results of transport and urban planning research offer various approaches to solving the problem of finding an effective ratio of urban transport types, while there is no established universal methodology. The following are several methodologies for optimizing the structure of passenger flow on the UPT developed in Russia:

1. D.S. Samoilov's methodology [4]. This method is based on distributing UPT work by groups of rolling stock capacity, in relevance with the population of the city.

2. Methodology of A.E. Gorev. In accordance with this methodology, each type of public transport has its own efficiency of use in the coordinates "carriage capacity - operating speed" [5].

3. Methodology based on the assessment of the passenger flow intensity. This method is based on a key indicator—the passenger flow intensity, measured in PKM, while determining the structure of the UPT systems is carried out on the basis of planning and socio-economic factors [6].

4. Methodology for the distribution of passenger correspondence by type of UPT based on pre-network modeling [7]. This approach is conducted on a set of tactical pre-network models that calculate the matrix of inter-district correspondence determined by structural movements in

the UPT group with given parameters for identifying the main functional zones in the city without taking into consideration the restrictions determined by the transport network.

Methodology

A. Litarature review

The study of the patterns of urban transport systems functioning for solving the pointed issue especially is impossible without the use of mathematical modelling methods. Tasks in transport and urban planning models are divided in the following groups:

- identifying the crucial features of the existing transport system;
- assessment of the consequences of decision-making on the transport system development;
- determination of the parameters of transport infrastructure objects based on the demand analysis for movement [8].

For more than half a century, mathematical models of transport and passenger flows have been developed in St. Petersburg (Leningrad) in collaboration with mathematicians and transport designers. Such organization of work ensures the effectiveness of the developed models, that are adapted to the solution of specific tasks in the framework of the development of transport and urban planning documentation. The publication [9] cites the works of recent years by international authors, who also recommend developing and applying such models only under the conditions of cooperation between mathematicians and transport engineers and urban architects.

A distinctive feature of the St. Petersburg (Leningrad) methodology for forecasting passenger flows is that it takes into account the patterns of mass behavior with a free choice of travel routes by all its participants [10]. The most complete approaches implemented within the framework of the St. Petersburg School of Transport Modeling are presented in the collection [11]. In this paper, V.P. Fedorov gave a detailed description of not only the main models for the passenger flows formation at the network, but also the information support the models, in particular, the transport graph, that are formatted in a rather laborious process.

It is shown in reference [12] that for a number of problems that do not require detailed results in terms of traffic distribution in the UPT network, it is advisable to use forecasting the volume of passenger flows based on a conditional transport graph presented as a regular grid - the so-called "pre-network" approach to model formation. At the same time, the most popular directions of movement in the city can become the basis (framework) of the UPT network. When using the described method, the territory of consideration is covered with a regular rectangular grid with a certain step; each node of this grid is connected by arcs to 8 neighboring nodes (including diagonals).

The proposed pre-network version of the model for the formation of passenger flows on a conditional transport network is developed on the V.P. Fedorov's model. On the arcs of a conditional transport graph, at the first step, the same initial speed is set, and then it increases or decreases based on a given function, that mainly depends on the amount of passenger flow (in a traditional network calculation, the speed on an arc depends on the type of transport and can only decrease depending on the amount of passenger flow). On the basis of the passenger flows and speeds formed on the arcs of the graph during the iterative process, high-speed routes can appear as a result of an analysis of the demand for transport movements, that depends primarily on the system of resettlement and employment places. The pre-network modeling method and the results of the corresponding experiments are presented in a number of works [13–16].

Pre-network modeling based on a regular grid allows you to get a predictive result with minimal effort. Separately, it should be noted that forming such models is focused on the key parameter γ, that corresponds to the average time spent on movement (in the entropy model for calculating transport demand the decrease in the probability of making correspondence with an increase in time costs is described by the so-called gravitation function, which is used as a function of the form $exp(-\gamma t)$. The adoption of the average travel time as a guideline for the formation of transport systems in transport and urban planning arose quite a long time ago. For the first time, the question of transferring the main operation parameters of the UPT to economic categories, namely the time spent on movement and the convenience of passengers, was raised back in 1932 by A. Kh. Silberthal [19].

The importance of this indicator for assessing transport systems is noted by many authors. Thus, in the publication [20], transport and planning criteria are given for assessing options for the general plan of the city. According to the authors, the first of the major transport and planning criteria used in assessing options for the development of the city is the time spent by the population on movement within the city and in its suburban area for labor, cultural and community purposes and on movement to the main foci of the population gravity.

E.A. Safronov notes [11] that the structure of the socio-economic assessment of the project assumes a direct and secondary effect, while the share of the secondary effect is from 70 to 90%. Saving travel time and reducing traffic fatigue are important factors in the side effect and account for about 70% of it [12]. This is an indicator of the excessive role of spending time (saving time). The role of the travel time valuation for efficiency determination is strengthened in the work of E.Yu. Muleev [13] on the base of the local and international scientific publications' analysis. The experiment was calculated indicators that make it possible to assess the feasibility of developing the subway network or its new construction in those cities where there is currently no subway (Perm, Tyumen).

Experimental procedure

The pre-network version of the model for the formation of passenger flows on a conditional transport network is used to assess the demand for high-speed transport in Krasnodar. The experiment estimated the load on the expert-designated hypothetical subway line by comparing under the conditions of resettlement systems and systems of the employment places adopted in 2007, 2017 and 2022 (the route of the subway line was designed on the data of 2017). The distinction of this model from the one described above is highlighting of changes in the assessment of the need to build a subway that causes an additional evidence base for its justification. These changes were identified based on a retrospective analysis of transport demand for the same city. It should be noted that the purpose of this experiment is to test the possibility of using the proposed model to assess the need for organizing high-speed transport in cities.

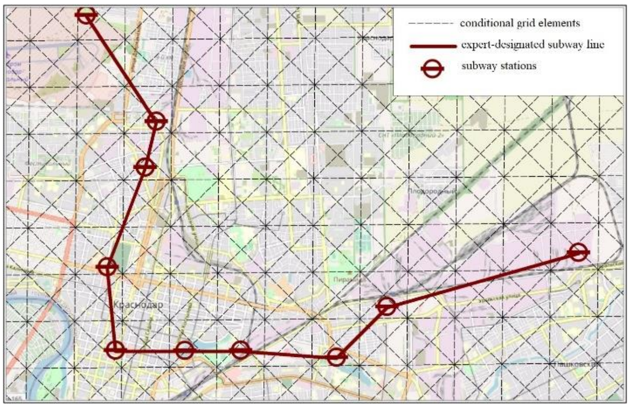

Fig.1. Expert-designated subway line for Krasnodar

The Krasnodar was chosen for the experiment due to the fact this city satisfies the criterion of reaching the one-million population threshold that is mentioned above. Furthermore, Krasnodar is a rapidly developing city, where the choice of priority areas for the formation of a public transport system is decisive at the current stage of its development. Simultaneously, the need to build a subway in Krasnodar is debatable: according to Oleg Kobzar, Honored Architect of Russia, "today it is absolutely unrealistic to build a subway in Krasnodar. This is a high-priced project. Although, this type of transport would really unload the transport system of our city. I think this issue should be discussed with the community of architects, who will share their professional opinion, taking into consideration the peculiarities of our city" [15].

As for the other cities presented above [14], within the framework of the experiment, a preliminary calculation of passenger flows was carried out on a conditional network (regular grid) without taking into account the subway; the most loaded arcs were considered as potential subway routes for the next calculation (Fig. 1). As for the other cities presented above [14], within the framework of the experiment, a preliminary calculation of passenger flows was carried out on a conditional network (regular grid) without the subway; the most loaded arcs were considered as potential subway routes for the next calculation (Fig. 1). The assumption is that industry distinctions of employment places are not taken into account in these experimental calculations. The correlation coefficient reflects the average ratio for all types of employment places. It should also be noted that inter-regional passenger correspondence that depends mainly on the size of the calculated transport areas in the traffic flow is not considered either.

The initial data on the population and places of employment for three calculation periods (2007, 2017, 2022) determined for each transport region (72 transport regions in total) were used. To form the population information base and the number of employment places for 2007 year for 72 transport regions, the information obtained in the course of carrying out transport calculations within the framework of the project [16] was used. For calculations for 2017 and 2022 years, the information base for the same transport areas was used in accordance with the social and economic development of the city. Meanwile, the authors used the population census data to correct the obtained indicators [17] (Table 2).

Table 2 – POPULATION AND NUMBER OF EMPLOYMENT PLACES IN THE ADMINISTRATIVE DISTRICS OF KRASNODAR TAKEN FOR CALCULATIONS.

	Districts	Population (in thousands)			Employments places (in thousands)		
		2007	2017	2022	2007	2017	2022
1	Central district	102.2	158.8	191.3	142.9	246.6	286.0
2	Western district	81.2	154.2	180.7	55.9	96.4	113.0
3	Karasun district	132.0	239.3	289.7	112.1	193.5	240.0
4	Prikubansky district	63.5	329.1	400.8	56.0	87.0	111.0

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