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Improving Methods of Estimation of Transport Demand for Urban Passenger Transportation

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***Abstract* — The article is devoted to the issues of the transportation demand estimation. Existing methods to bring up to date the Origin-Destination matrix are reviewed. A regression method to update the passenger Origin-Destination matrix is proposed. The proposed method is compared with the method of calculating the Origin-Destination matrix using the population mobility data. The comparability of the proposed method with the standard method of calculating the Origin-Destination matrix is established. The characteristics of the transport mobility of Irkutsk city population are also established. The relevance of the research topic is determined by the growth of the level of vehicle-to-population ratio and transport mobility of our country population that complicates the process of designing and managing urban passenger transport systems (UPT). One of the urgent objectives is the development of efficient methods to estimate the demand for transportation services, including ones to determine the distribution of this demand between UPT and individual road transport. Constantly updated information on transportation demand improves the efficiency of the management of the UPT system and improves the quality of transportation services provided to the population.**

Keywords — transport and urban planning, transportation demand, origin-destination matrix, travel time distribution, urban passenger transport.

I. INTRODUCTION

The problem to estimate the existing flow distribution and travel transportation demand is relevant by focusing on issues of either organization of road traffic (the distribution of vehicle flows along the road network) or organization of passenger traffic (distribution of passenger traffic through the passenger transport network), that is why it can be called universal. The Origin-Destination (OD) matrix is the most important form of describing the mobility demand, and in the case of the existing transport network, the existing Origin-Destination matrix.

The OD matrix was previously calculated in some large cities and, currently, it does not reflect the real situation of the transport demand distribution, consequently there is the need to calculate a new one. To calculate the matrix by determining the population mobility data is time consuming and not always possible. Therefore, it is very important to develop methods and techniques to update such OD matrices that do not require time-consuming surveys to obtain baseline data, and also provides the ability to perform rapid updates using automated means of passenger check-in.

The problem of determining transportation demand and flows distribution according to the results of a sample survey of passenger and transport flows in the transport network was considered by many authors, our country including.

One of the most comprehensive reviews of the OD matrix reestablishment methods based on measured passenger traffic and traffic intensity is presented in the Austrian report of the International Institute for Applied Systems Analysis (IIASA) [1], which systematized papers on this topic issued during last 30 years. This report proposes the following classification of the OD matrix estimation methods (Fig. 1):

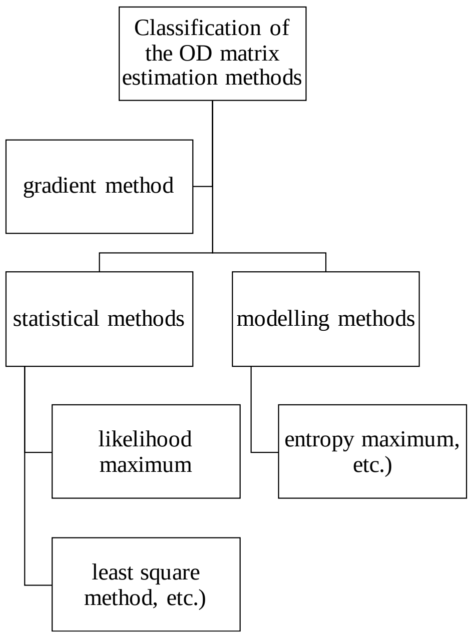

Fig. 1. Mathematical approaches to estimation of the traffic flow distribution using traffic intensity data

The most general formulation of the problem is developed by T. Abrahamsson. He believes that in the most general form, the algorithm to reestablish the OD matrix is formulated as follows:

$$min(g,v) = y_1F_1(g,\hat{g}) + y_2F_2(v,\hat{v}) \quad (1)$$
$$g,v \geq 0 \text{ if assumption } v = assign(g),$$

where $\hat{g}$ is possible to be reestablished Origin-Destination matrix; $\hat{v}$ is a vector of values of observed flows; F_1 and F_2 are some distance measures; y_1 and y_2 are concordance coefficients; *assign (g)* is flows distribution over the network, dividing the Origin-Destination matrix $g_{(i,j)}$ into flows moving along different routes.

For example, Bell M.G. [2, 3] proposed an OD forecast model in which the network flows are taken as a whole, without separating the components typical for individual OD pairs of areas. Such approach is undoubtedly associated with the simplicity of obtaining data (i.e., it is only necessary to measure network flows), in addition, in such a case, it is possible to use devices that capture the values of transport flows automatically (transport detectors of various types). The lack of detailed information reduces significantly the accuracy of the forecast in such a model; however, some of the approaches used in it are quite general in nature and can be used in cases where more detailed information about the flows is available.

The above-described OD matrices estimation methods make it possible to identify their general characteristic: the availability of presented in various forms information on the existing distribution of passenger and transport flows or the presence of an “old” OD matrix. Any preliminary information on the flows distribution improves significantly the accuracy of the OD matrix estimation [1-8].

II. Methods and Materials

The set by the author objectives include the development of a methodology suitable for updating the previously calculated OD matrix under the following conditions:

- detailed representation of the network in the form of an oriented graph is considered, on specially selected sections of which, the passenger traffic flow is set by measurements;
- passengers flow surveys’ data are used (manual or automatic counting, video recording followed by subsequent processing, output entry sensors, etc.);
- the previously calculated OD matrix (master plan materials) is used, as well as cartogram of passenger flows obtained by this matrix;
- OD matrices between the selected vertices of the network are determined by the methods of mathematical statistics, i.e. using robust regression analysis [7-9].

Due to the absence of preliminary information on routes, the submission of initial data to estimate the OD matrix is necessary in order to connect each pair of mutually corresponding points by one and the same route. Such a description of the network makes possible to decompose the problem of estimating the OD matrix, considering the transport network both as a whole and as a series of smaller sections. The transport network can be considered as a set of directed graphs, in which each corresponding pair of vertices presents only one route. In other words, decomposition is reduced to the division of the studied network section into graphs, the distribution along all-or-nothing routes can be applied to determine the matrices of which.

The purpose of estimation [8] is to find such an origin-destination vector $\hat{x}$, where the corresponding passenger traffic at the links of the network $\hat{y}$ corresponds to the measured value of the passenger traffic y as closely as possible:

$$\sum_{i=1}^{n}|e_i|^v = \sum_{i=1}^{n}|y_i - \hat{y}_l|^v \to min \qquad (2)$$

where y_i is the measured values of the flow rate at the links of the network; e_i are errors of convergence of intensity values (regression residuals); v is a sensitivity coefficient $1 \le v < 2$.

In linear programming, the estimated parameters are limited by the sign ($\hat{x} \geq 0$). To avoid such an assumption, the implementation of the smallest modulus method (MNM) requires the input of additional variables that enable the inclusion of regression residues into the linear programming objective function.

To use linear optimization methods (Matlab package Optimization Toolbox library is used), slack variables are introduced into the vector of evaluated correspondences x, vector of regression residues e. Thus, the algorithm, with reference to the reestablishment of OD matrices, is as follows:

$$min \sum_{i=1}^{n}|e_i| = \min\left(f_j^T x2j\right), \qquad (3)$$

if linear assumptions on variables

$$A2 \times 2 = y, \qquad (4)$$

and bilateral assumptions on the estimated parameters vector

$$xlb \leq x2 \leq xub, xlb \geq 0, xub > 0.$$

III. Results of the Analysis

To apply the discussed above method, it is necessary to use some initial value of the estimated parameters $\hat{x}_j^0$. The proposed algorithm is suitable for the case when the initial data is represented by the values of passenger traffic, and prior OD information is presented in the form of a previously calculated (“old”) OD matrix. In our work, the “old” matrix was adopted based on Irkutsk General Plan materials, prepared by the Central Research Institute of Urban Development in 1985–1987. It also defines the transport zoning of the city (Fig. 2).

Applying the suggested algorithm, the authors performed an experiment in relation to a real-life network of urban passenger transport and the updated OD matrix was obtained as the result. The type of the analyzed graph of the urban passenger transport network is presented in Fig. 3.

The further objective was to calculate another OD matrix based on the population mobility data. It was necessary to compare obtained in two different ways matrices.

On the basis of a selective survey of the population, the basic data were obtained to calculate the passenger OD matrix, such as: population mobility, travel time distribution (gravity curve – Fig. 4), etc. According to the data obtained using the gravity model and the travel time distribution, the passenger OD matrix was calculated [11–17].

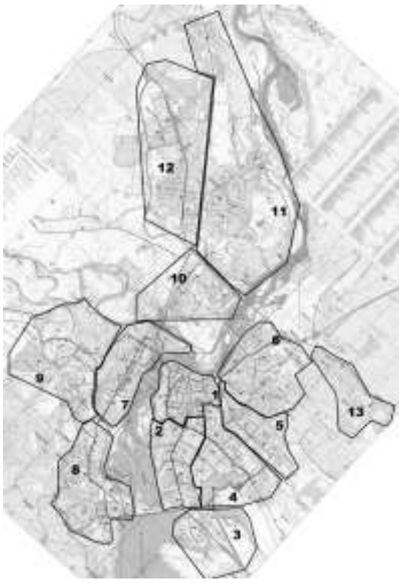

Fig. 2. Division of the city territory into integrated transport zones

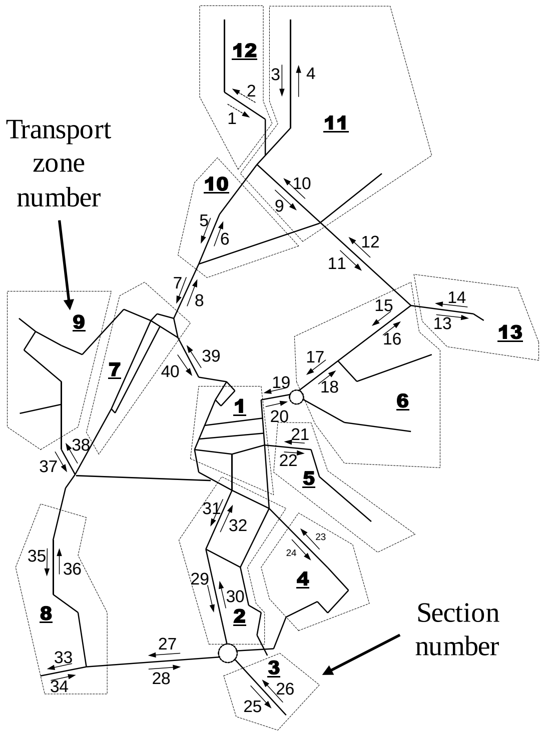

Fig. 3. City transport network presenting selected sections

The daily all-purposes travel expenses of the population and the average duration of one-way travel, as well obtained as the results of the survey, are presented in Table 1.

Thus, in particular, it can be noted that according to the results of the survey it was identified that SNIP requirements 2.07.01-89* for permissible time expenditure are not met. The time spent by the population on travelling for labor purpose is 38 minutes only in the case of 55% of respondents (Fig. 5).

TABLE I. IRKUTSK CITY NETWORK INDICATORS, ESTIMATED BY THE SURVEY RESULTS

No.	Indicator	Value
1	General mobility *travels/day per 1 person*	2.46
2	Network mobility *travels/day per 1 person*	2.33
3	Route mobility *trips/day per 1 person*	4.06

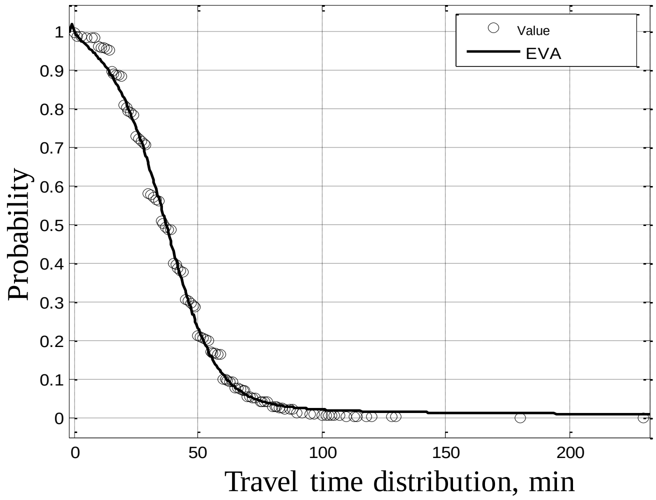

Fig. 4. Gravitation curve built using selective questionnaire data based on the EVA model

Among the factors contributing to the high travel time expenditures for labor purposes are:

- high time required to reach stopping points (average values are 4.6–6.7 min);
- high costs of time for transfers (average values are 6.6–12.6 min)

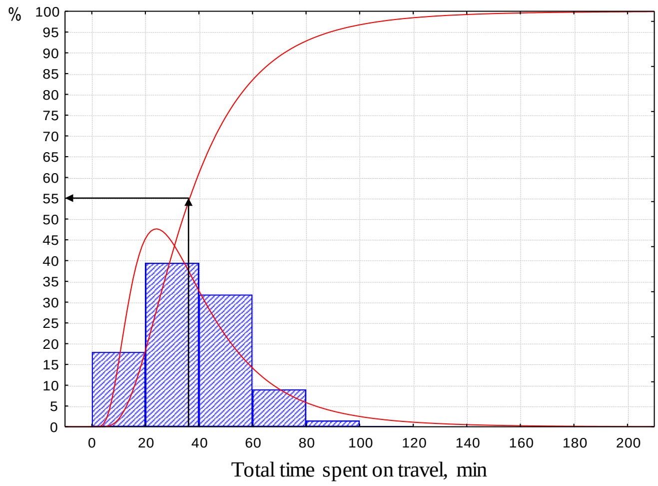

Fig. 5. Allocation of time spent on one-way travel for labour purpose

At the final stage of the study, the author compared the matrices obtained by two different methods (Fig. 6 and Table 2).

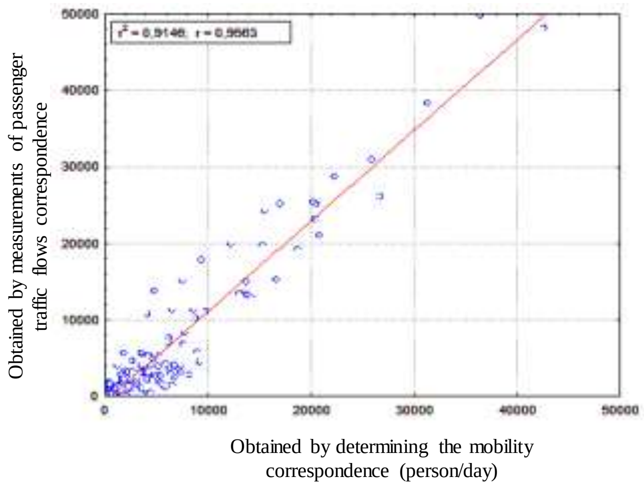

Fig. 6. Correspondence Scatter Chart, estimated in two ways

TABLE II. COMPARISON OF ESTIMATED IN TWO WAYS CORRESPONDENCE VALUES

Statistics	R	R^2	$\hat{t}$ - for pairs difference
Statistic values	0,95	0,91	1,14

The scatterplot and correlation indices show that the being compared matrices belong to one and the same general population. However, the majority of statistical evaluation criteria are based on the normality of sample distribution. It is obvious that correspondence does not obey the normal law, it is necessary to use static criteria that do not require normal distribution. The significance of the average difference of pairs was checked using Student's *t*-test, which is recognized in the statistical literature as the optimal criterion for the method of pair comparisons [18, 19]. The coefficient of Student $\hat{t}$ when comparing the two matrices amounts to 1.14; it does not exceed the critical value $t_{(0.05;\ 155)}$ = 1.96. (Table 3)

TABLE III. STATISTICAL COMPARISON OF TWO METHODS

Compared parameters	Average	N	Standard deviation	t	df
Correspondence calculated	5303.583	156	2890.55	-1.148	155
Correspondence updated	5569.301				

IV. Conclusions

The results show that the proposed method of regressive passenger OD matrices updating using data of passenger flow measurements and previously calculated "old" OD matrix as the initial approximation is comparable in accuracy to the method of calculating OD matrices based on population mobility data. This method will reduce significantly the time to calculate the passenger OD matrix, as well as the money spent.

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