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SIMULATION PROCEDURE OF ORIGINAL-DESTINATION MATRIX BASED ON SAMPLE SURVEY RESULTS BY CARD METHOD

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Abstract. *A new method for forming the matrix of passenger correspondences based on the results of field investigations on the route network is developed. The procedure of determining the matrix of network correspondences presupposes the implementation of 3 stages that the appropriate parameters of demand for transportation are based on each of them. The key aspect of the method developed is considerable reduction of labour-effectiveness of carrying out inspections on condition of preserving sufficient appropriateness of the data of the common massif.*

Key words: *trip, original-destination matrix, bus stop capacity, route network.*

МЕТОДИКА МОДЕЛИРОВАНИЯ МАТРИЦЫ СЕТЕВЫХ КОРРЕСПОНДЕНЦИЙ НА ОСНОВЕ РЕЗУЛЬТАТОВ ВЫБОРОЧНОГО ОБСЛЕДОВАНИЯ ТАБЛИЧНЫМ МЕТОДОМ

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Аннотация. *Представлена методика моделирования матрицы сетевых корреспонденций для средних и больших городов. Предложено моделировать значения величин пассажирских корреспонденций на основе результатов обследований пассажирообмена остановочных пунктов по зафиксированным рейсам с дальнейшим их формированием в матрицы маршрутных корреспонденций.*

Ключевые слова: *пассажирская корреспонденция, матрица корреспонденций, емкость остановочного пункта, маршрутная сеть.*

МЕТОДИКА МОДЕЛЮВАННЯ МАТРИЦІ МЕРЕЖНИХ КОРЕСПОНДЕНЦІЙ НА ОСНОВІ РЕЗУЛЬТАТІВ ВИБІРКОВОГО ОБСТЕЖЕННЯ ТАБЛИЧНИМ МЕТОДОМ

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Анотація. *Подано методику моделювання матриці мережних кореспонденцій для середніх та великих міст. Запропоновано моделювати значення величин пасажирських кореспонденцій на основі результатів обстежень пасажирообміну зупинних пунктів за зафіксованими рейсами з подальшим їх формуванням у матриці маршрутних кореспонденцій.*

Ключові слова: *пасажирська кореспонденція, матриця кореспонденцій, місткість зупинного пункту, маршрутна мережа.*

Foreword

The main task of the route system organization of city passenger transport is compilation rational scheme of routes with definition them routs and haulage capacities. Source information for implementation of these actions is original-destination network matrix, which reliability of data provides the correct solving of routing questions and development the passenger network of the city.

Analysis of published works

In most cases the travel demand modeling techniques are based on correspondence determination between two i and j urban zones being transport districts [1]. The methods to determine the correspondence matrix can be divided in two branches. The first one is called the extrapolation methods. It can be referred to this group of such approaches as «the single growth coefficient method», «the average growth coefficients method», «Detroit's method» and «Fretter's method» [2]. The calculation of travel demand on passenger transport use listed above the approaches may be executed by the followed formula

$$D_{ij}^{/} = D_{ij} \cdot k_i \cdot k_j \cdot \frac{M_i + M_j}{2}, \qquad (1)$$

where D_{ij} – the existing passenger correspondence between two transport areas, pass.; k_i, k_j – the growth coefficients of passenger traffic accordingly in the areas of departure and arrival; M_i, M_j – local factors of the areas i and j.

The disadvantage of exponential methods is the low exactitude of obtained results.

The second group of original-destination matrix formation is called «methods based on the apriory logical hypothesis» [3]. Among the methods of this group the gravitation models are widely used that is why this method needs to be deeply analyzed. In bases of gravitation models there lies the physical axiom «with the distance growth between two objects the attraction reduces». From this position it was assumed that with the trip distance growth the number of passenger trips decreases. This statement finds its implementation in formula (2)

$$A_{ij} = k \cdot \frac{A_i^{\alpha} \cdot A_j^{\beta}}{R_{ij}^{\gamma}}, \qquad (2)$$

where k – is a scale coefficient; A_i, A_j – are capacities on departure and arrival accordingly, pass.; R_{ij} – is the resistance function of transport connection areas i and j; α, β, γ – are empirical coefficients obtained as a result of full scale investigation.

The main problem of the gravitation model application is connected with necessary of its calibration. The author in the work [3] proposed the approach for eliminating of this necessity using Lagrange's multiplying factors optimization method. The calculation of passenger correspondences was proposed to realize using the formula (3)

$$F(h_{ij}) = \sum_{i=1}^{n} \sum_{j=1}^{n} (b_{ij} - h_{ij})^2 \to \min, \qquad (3)$$

where b_{ij} – the ideal correspondence; pass.; $F(h_{ij})$ – the sum square deviation of the calculated correspondences from the ideal on; h_{ij} – calculated trips, pass.

In spite of possibility to obtain the correspondence matrix without the necessity of model calibration the method [3] has a disadvantage. It lies in using as the resistance function only transport factors such as the travel cost, distance or travel time [4].

Object and set of a problem

The object of the research is the development of the simulation procedure of original-destination route matrix based on the table observation results of passenger rotation on bus stops. As the object of the research is considered the passenger service process of middle and large cities on the route network. The subject of the research is regularities of formulation of the bus stop departure capacity and their impact on the value of route passenger correspondences.

Simulation procedure of original-destination route matrix

The best method of getting of the matrix passenger correspondences is observation of movement of the city passengers in the transport network. In case of considering public transport the observation relates only city routes, the act of which with passengers implements on the equipped or not equipped bus stops.

The more reliable and popular is table method of city route observation and it provides only information about quantity passengers which load into route transport unit or left it. Such kind information is enough for total rating of the traffic volume but it doesn't reflect correspondences on the route.

In order to convert the bus stops capacity to value of correspondences between pair of the bus stops it is necessary to predict the technique of the correspondences based on plausible hypotheses about passengers unloading from the vehicles on the bus stops. Basis for building municipal matrix of correspondences in this case is regular matrix of correspondences for all routes and all runs operated during the observation period. It is morning peak or one day as usual.

$$\mathrm{H_c} = f(\mathrm{H}_m, k_n), \qquad (1)$$

where H_c – matrix of network correspondences; H_m – matrix of route correspondences; k_n – coefficient of passenger rotation.

When the number of transfer in transport is small in the route network and it may be neglected the municipal matrix of correspondences represent the simple sum of run matrices correspondences. Each matrix route correspondences H_m is formed from the run correspondences on the route during a particular period of time

$$\mathrm{H_m} = \{h_{pl}\}, \qquad (2)$$

where h_{pl} – the value of passenger route correspondence between bus stops p and l during a particular period of time, passenger.

For the purpose of these methods the route network of the city is represented in the form of a plurality of bus stops

$$\mathrm{P} = \{p_1, p_2, ..., p_N\}, \qquad (3)$$

where p_i – bus stop; N – the number of bus stops in the network, pc.

In its turn each run correspondence h_{pl} represents quantity of the passengers which move between buses stops p and l. At that each operate bus on the route makes some quantity of runs each of them is indicated as A_i. The total quantity of runs during period on the route is represented as plurality

$$\mathrm{A} = \{A_1, A_2, A_i, ..., A_Z\}, \qquad (4)$$

where A_i – i-run in the route system; Z – total quantity of the runs which operate in the route system during review period, pc.

In general it's not possible to cover all quantity of the runs in observation therefore it is necessary to realize the sample observation. In this case the question is about method formation and volume of runs sampling frame.

For solving this question it was made presurmise that all routes have approximate similar attraction for passengers, i. e. it is absent advantages in choosing the route and passengers board in the first bus that follows from p to l.

The bus quantity on every route, in which the checkers are, represents the sample from the general number of the buses from the routes. So it is obviously that not the every run (bus) is checked because of large scale of the medium and big cities. In such conditions the general number of the checkers is n and every checker can fix only some number of the run trips h_{ipl}, which are the sample from general amount of the runs between bus stops p and l. So the first conclusion can be made – the more route runs have been fixed h_{ipl}, the more accurate the estimation of the total volume of the trips h_{pl} will be.

Based on this the task is to determine the number of the runs which have to be checked that will allow to predict the general totality h_{pl} taking into account the given level of confidence P.

According to that the follow equality has to be performed

$$h_{pl} = \sum_{j}^{A} h_{jpl}, \qquad (5)$$

where j – the bus index.

It has to be noticed that as the result of the survey the investigator obtained only some sample of the general totality. That leads that obtained volume of the trip run between some bus stops p and l will be less than general number. So the special coefficient of harmonization has to be established which will align the obtained data with the real one. For public transport this coefficient is can be formalized as:

$$C_k = \frac{A_k}{a_k}, C_k \geq 1. \qquad (6)$$

If $C_k = 1$, the survey is not the selective, it is general.

As the result of multiplying the coefficient on trip volume between bus stop p and l we obtain numerical row

$$C_1 \cdot h_{1pl} + C_2 \cdot h_{2pl} + C_3 \cdot h_{3pl} + ... + C_n \cdot h_{npl}, \quad (7)$$

where h_{npl} – passenger trip on the n route, which is particularly, is the random number, pass.

Using the table method it is impossible to fix the trip volume between some pair of the bus stops. But on the base of the survey results for example the number of passenger which entered the route vehicle till certain bus stop is can be defined

$$D(j) = D_i + D_{i+1} + D_{i+2} + ... + D_{j-1}, \quad (8)$$

where D_i – the quantity of the passengers which entered the vehicle on i bus stop, pass.

Respectively, the passenger volume, that left the route vehicle till j bus stop is defined as

$$A(j) = A_{i+1} + A_{i+2} + ... + A_{j-1}, \quad (9)$$

where A_{i+1} – the volume of passengers that left the vehicle on i+1 bus stop, pass.

It is obviously that (8) is equal to (9). On the base of that we can make the mathematical estimation of the volume of the route trip

$$\bar{h}_{ij}(m) = \frac{D_i}{D(j)} \cdot A_j. \quad (10)$$

Obtained capacities of the bus stops allow to execute simulation of the original-destination matrix for the one run in two directions.

But the main task is obtaining the day original-destination matrix on survived route. For that it is necessary to have the data about trip rotation on all runs on the route, what under condition of the sample survey is can't be performed. In such condition it is occurred the necessity of using the simulation of bus stop capacities on the base of theory of probability and mathematical statistics. The hypothesis having been put forward is the capacity of the bus stop is random discrete value that is distributed according to Poisson. The results of sample survey on the Okhtyrka city route network are taken as statistics.

The survey has been carrying out for 5 days in period from 10 till 14 November 2014. The route network of Okhtyrka city consists of 29 bus routes on which operate 35 vehicles. The sample survey is stared every day at 6:30 a.m. and finished at 6 p.m. It has been inspected 170 runs for the all period of the survey. On every observed unite (run) it has been checked the hypotheses about accordance with Poisson. The figures 1 and 2 show the example of histogram of empirical frequency distribution and given estimation of their consistency with the theoretical distribution of the random variable.

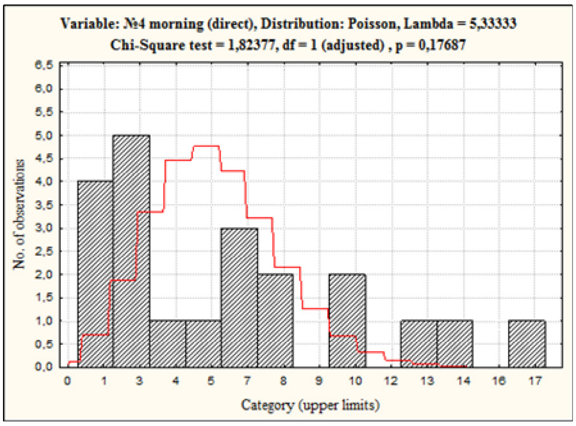

Fig. 1. The histogram of bus stop capacities distribution on route №4 in direct direction

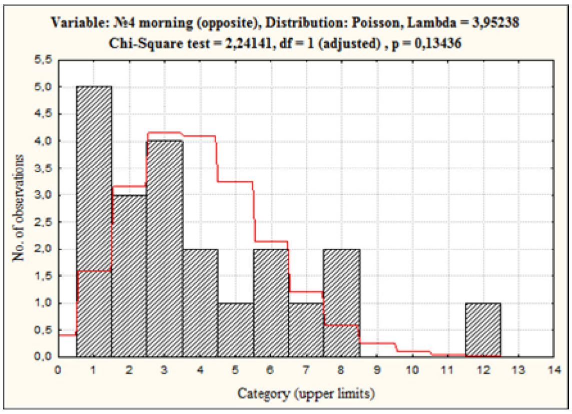

Fig. 2. The histogram of bus stop capacities distribution on route №4 in opposite direction

So, hypothesis did not refute, that is why the probability of D quantity of passengers which came to the bus stop will be simulated like

$$p(D) = \frac{\lambda^D}{D!} \cdot e^{-\lambda}, \quad (11)$$

where λ – the parameter of distribution low; D – the volume of the passengers that can come to the bus stop during a period of time, pass.

The day period of routes working has been separated on 3 terms: middle rush period, morning and evening rush period. On the base of the results of the sample survey it has been determined the numerical values of the parameter λ. The results are showed in the table 1.

On based data from table 1 it was made modeling of the matrix passenger trips for all runs on the route of Okhtyrka city. The example of the one run matrix trips is indicated on the fig. 3.

Table 1 The numerical values of the parameter λ on bus routes in Okhtyrka city

Route number	Observation period					
	morning rush period		middle rush period		evening rush period	
	direct direction	opposite direction	direct direction	opposite direction	direct direction	opposite direction
1	2,78	2,45	2,54	1,05	–	–
1a	2,11	2,26	–	–	–	–
2	2,5	1,9	–	–	2,22	1,6
11a	2,42	2,07	–	–	–	–
16	2,81	2,16	–	–	2,63	2,45
18	–	–	2,85	1,8	3,6	2,38
20	1,4	2,9	–	–	–	–
22	4,11	2,15	–	–	2,5	1,8
23	–	–	–	–	3,85	2
11	2,42	2,08	–	–	–	–
24	1,42	1,8	–	–	–	–
5	2,82	3,35	2,55	1,17	–	–
5a	–	–	1,75	1,13	–	–
4	5,33	3,95	1,96	1,88	–	–
9	1,9	2,45	–	–	3,87	3,17
25	–	–	–	–	2,23	2,54
17	2,63	3,27	–	–	2,81	2,67
14	–	–	–	–	2,2	1,12
8	1,87	4,43	1,31	0,75	–	–
15	–	–	1,67	0,6	–	–
7	2,81	2,69	–	–	1,67	2,67
10	2,46	2,22	–	–	2,13	2,33
6	3,5	2,95	–	–	2	2,9
13	–	–	–	–	2,28	2,63
3a	3,96	3,62	–	–	2,91	3,54

The sequence number of stop	1	2	3	4	5	6	7	8	9	10	11
1		0	0	0	0	1	3	2	0	0	0
2			0	0	0	1	6	5	0	0	0
3				0	0	1	3	2	0	0	0
4					0	0	1	0	0	0	0
5						0	1	0	0	0	0
6							0	0	0	0	0
7								0	0	0	0
8									0	0	0
9										0	0
10											0
11											

Fig. 3. Run matrix correspondences on the route 3A run 6:58 traffic in transit

It was assigned numbers for all bus stops based on their belonging to transport hubs. The next step is determination of the affiliation of each bus stop to the appropriate transport area.

In this case the transport area will consist of some quantity bus stops, i.e.

$$\mathrm{R} = \{p_1, p_2, p_3, ..., p_q\}, \qquad (12)$$

where R – plurality of bus stops that characterizes the transport area; q – number of the bus stops which are included to transport area, pc.

Accordingly, it will satisfy the condition

$$Z = \bigcup_{i=1}^{r} \mathrm{R}_i, \qquad (13)$$

where Z – plurality that formed by the transport areas and reflects the territory of the city.

The result of Okhtyrka city area separation on the transport areas is shoned on figure 4. It should be mentioned that on the route network the transport service is executed in regime «route taxi». This causes performance by route vehicles the stops at the request of passengers. That leads to increase of complexity of original–destination matrix simulation. The sample of the route O-D matrix represented of fig. 5.

Based on described method it's been done modeling 680 original-destination run matrixes which were then aggregated into 58 routes matrixes (direct and opposite directions).

The result of the research is formed from 58 routes matrixes final network original-destination matrix for all work day of passenger transport in Okhtyrka city.

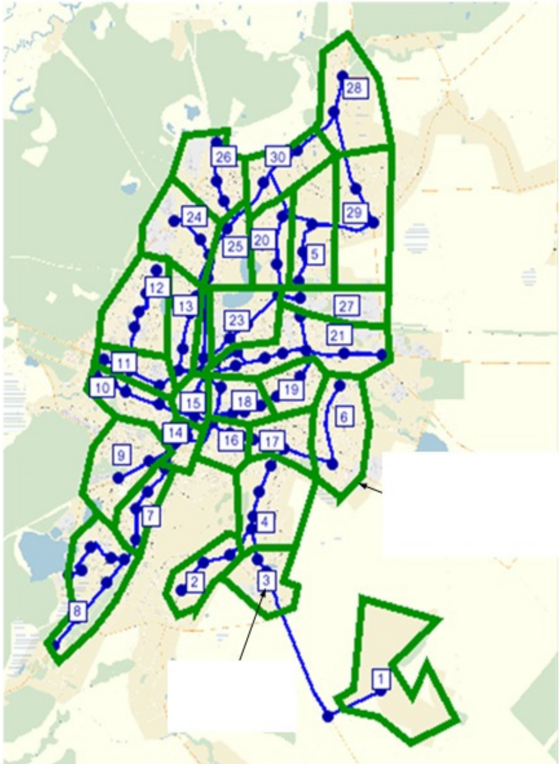

Fig. 4. Result of separation the city territory on the transport area

Stop number	952	846	679	929	509	1005	1013	351	317	1012	946	181	143	949	39	1011
952		4	3	0	8	2	3	2	3	6	9	4	0	1	0	1
846			4	1	3	2	2	3	4	5	10	6	1	1	0	1
679				1	6	1	3	2	4	5	5	3	0	1	0	0
929					8	0	3	0	2	2	2	2	0	0	0	0
509						0	2	1	11	4	2	0	3	0	0	0
1005							3	3	3	3	1	1	0	1	0	1
1013								0	0	3	3	3	0	1	0	0
351									0	3	1	1	1	0	0	0
317										1	1	0	0	0	0	0
1012											0	1	0	0	0	0
946												1	0	1	0	0
181													0	0	0	0
143														0	0	0
949															0	0
39																1
1011																

Fig. 5. Original–destination matrix in direct direction on route №3A

Conclusion

The developed method of route original–destination matrix simulation allows to estimate the volume and the scale of the existing demand of city population on passenger network service. It can be executed on the base of sample survey of passenger traffic with further random generation of original–destination run matrixes.

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