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Establishing Patterns of the Urban Transport Flows Functioning On Urban Network Parameters

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Abstract

Patterns of formation of traffic flows in cities is estimated through indicators of reserve capacity, transport work and the load factor of the road. Solutions to the modern traffic organization problems was achieved through evaluation of these indicators with surveys carried out for various types of streets and roads: main streets and roads of citywide regulated traffic, main streets and roads of regional significance, streets and roads of local importance. The transport flows patterns on the level of motorization are presented.

Keywords: road traffic, transport network, motorization level, traffic characteristics

1. Introduction

The aggravation of transport problems in large cities and cities of Ukraine in particular, is associated with an increase in the ownership of individual vehicles (Gyulyev, et. al., 2018; Lobashov, et. al., 2018). The phenomenon takes place against the backdrop of the development of transport networks lagging behind the needs of road traffic. The number of vehicles owned by the individual owners has been taken to compare with the motorization level. Therefore, an approach developed to determine this indicator and its impact on the parameters of traffic flows is relevant.

The analysis of modern transport problems revealed shortcomings in the process of managing urban traffic flows. References analysis on this issue shows the use of different approaches to evaluation of the motorization level (Lobashov, Burko, 2017). In (Yannis, et. al., 2018), the use of data extrapolation methods, the results of constructing

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the funnels of the forecast, as well as models based on multifactorial correlation were proposed to calculate this index. The motorization level was proposed to be determined depending on the growth forecast of the gross regional product, and based on the possibilities of the urban transport infrastructure, the motorization level was predicted (Antoniou, et. al., 2016; Litman, 2017) determine this indicator on the basis of the value of per capita income. The disadvantages are related to the unsatisfactory level of traffic accidents (Afanasieva, Galkin, 2018), the lack of development of transport networks against the motorization level raising. The aim of the research is establishing the patterns of the urban transport flow functioning on urban network parameters.

2. Materials and methods

The functional interrelation of the motorization level, the parameters of the urban transport network, the traffic flows characteristics can be shown in Fig. 1. The first part of the figure presents methods for determining the prospective traffic intensity at the sections of the transport network. To determine the prospective intensity of movement, various methods can be used, which can be divided into several groups: extrapolation methods, analogy methods, expert assessment methods. Extrapolar methods include: linear function (Patriksson, 2015; Polson & Sokolov, 2017), non-linear function (Zhao, 2017), prediction using the formula of compound interest (Qu, Zhang & Wang, 2017). Analogy methods: the Fratar method and the Detroit method (Patriksson, 2015), the method of the simple-factor growth and single growth factors (Rao & Rao, 2012). The third type of methods is expert assessment methods (Sundaram, S. et al., 2010). In addition, it is possible to use the methods of limited capacity, specific mobility, the synthetic method, the method of shortening and distribution to a greater number of routes (Wald, 2004; Fuentes, et. al., 2017). The authors proposed to use the method of a single growth rate, taking into account considering changes in the automobilization level, quanity of inhabitants, the average price of a car and purchasing power of inhabitants (Galkin, et. al, 2018).

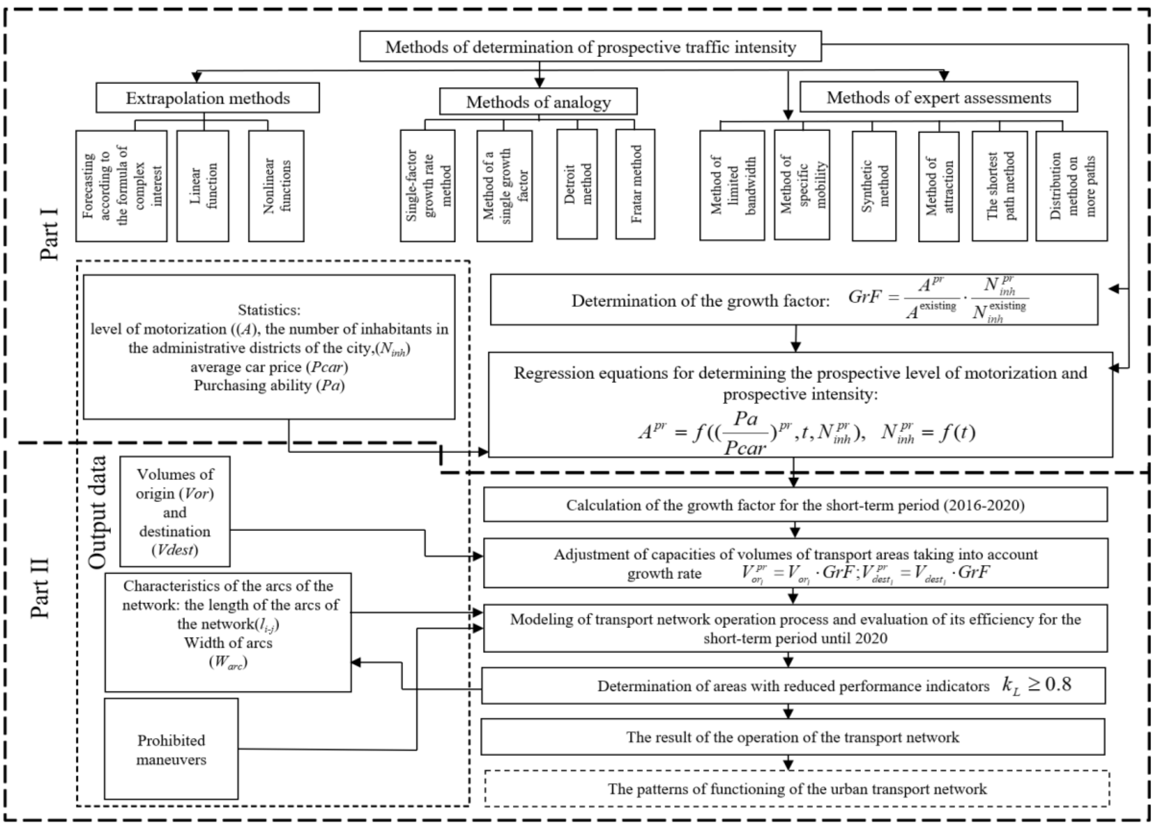


Fig. 1 – Structural scheme of research

Using growth factors, traffic volumes in the transport areas are adjusted. Annual Average Daily Traffic method was presented by Gecchele, et., al., (2011). In the second part of Fig. 1, the topological network of Kharkiv (Ukraine) is developed, which has 842 nodes and 2362 arcs. Each connection was described mathematically using graph theory. For example, in one-way traffic, the oriented graph was used. To determine the characteristics of the sections of the transport network and transport hubs, surveys were conducted on the network of the city of Kharkov. In the course of the survey, such basic data were collected as: intensity, velocity of traffic flow and a number of other characteristics. The capacity of the Demand and supply of traffic flows in the nodes, which contain information on transport movements were identified. On the transport network, arrival is carried out both within the network and at the edges. At the edges of the network, transport demand is equal to the intensity of incoming external transport. In the transport network itself, the transport demand is determined on the basis of the conditional boundaries of the transport area and distribution of traffic flow.

To analyze the distribution of traffic flows on the urban transport network the gravity method is used for predicting correspondence in the transport network. The initial data for calculating the correspondences matrix are the origin-destination (O-D) demand of traffic flows in the network, the characteristics of the network, and (O-D) distance matrix.

Overall, correspondence from node *i* to node *j* is calculated by the formula:

$$H_{ij} = Vor_i \cdot \frac{Vdest_j \cdot D_{ij} \cdot K_j}{\sum_{t=1}^{n} Vdest_t \cdot D_{it} \cdot K_t}, \tag{1}$$

where Vor_i - volume of origin from the i-th node, u / h; $Vdest_j$ - volume of destination in the *j*-th node, u / h; D_{ij} - the function of the *i*-th and *j*-th nodes; K_j - balancing factor; *n* - number of nodes in the transport network.

The function of the network between nodes, depending on the optimization criteria is determined by the formulas:

$$D_{ij} = L_{ij}^{-1}, \qquad D_{ij} = C_{ij}^{-1}, \qquad D_{ij} = T_{ij}^{-1} \tag{2}$$

where L_{ij} – distance between nodes *i* and *j*; C_{ij} – transportation costs unit for vehicle travel between nodes *i* and *j*; T_{ij} – travel time between nodes *i* and *j*.

After distribution of all correspondence over the network, it is possible to determine the parameters of the transport network activity as a whole.

The efficiency of the transport network is determined in accordance with one of the three criteria, taking into account the projected traffic intensity along the arcs of the network. The software presupposes the use of the following criteria of the transport network functioning effectiveness: total transport costs of all vehicles (C_{tr}); total network mileage (L_{tot}); total driving time (T_{tot}).

The efficiency criterion is calculated using one of the formulas:

$$C_{tr} = \sum_{i=1}^{k} N_i \cdot C_{tri}; \qquad L_{tot} = \sum_{i=1}^{k} N_i \cdot L_i; \qquad T_{tot} = \sum_{i=1}^{k} N_i \cdot T_i; \tag{3}$$

where N_i - traffic flow on the i-th arc, units / h; k - number of arcs of the transport network.

The motorization level is associated with the characteristics of traffic flows (Schlosser, Schlosser, 2016; Saha, Sarkar & Pal, 2017). The traffic flows characteristics are interrelated with the parameters of the transport network and the indicators of its functioning (Nuzzolo, Crisalli & Comi, 2015; Lobashov & Burko, 2017). The impact of the motorization level on transport demand is proposed to be estimated by the coefficient of growth of traffic volumes in the urban zones. Weighted average traffic load factor ($k_L^{av.weighted}$):

$$k_L^{av.weighted} = \frac{\sum_{i=1}^{n} k_{L_i} \cdot N_i}{\sum_{i=1}^{n} N_i}, \tag{4}$$

where k_{L_i} – the load factor of the *i*-th arc of the transport network; N_i – intensity of movement on the *i*-th arc; *n* – number of arcs of the network.

Reserve of the road capacity (R):

$$R = \frac{\sum_{i=1}^{n} P_i - N_i}{n}, \tag{5}$$

where P_i – road capacity, car/h.

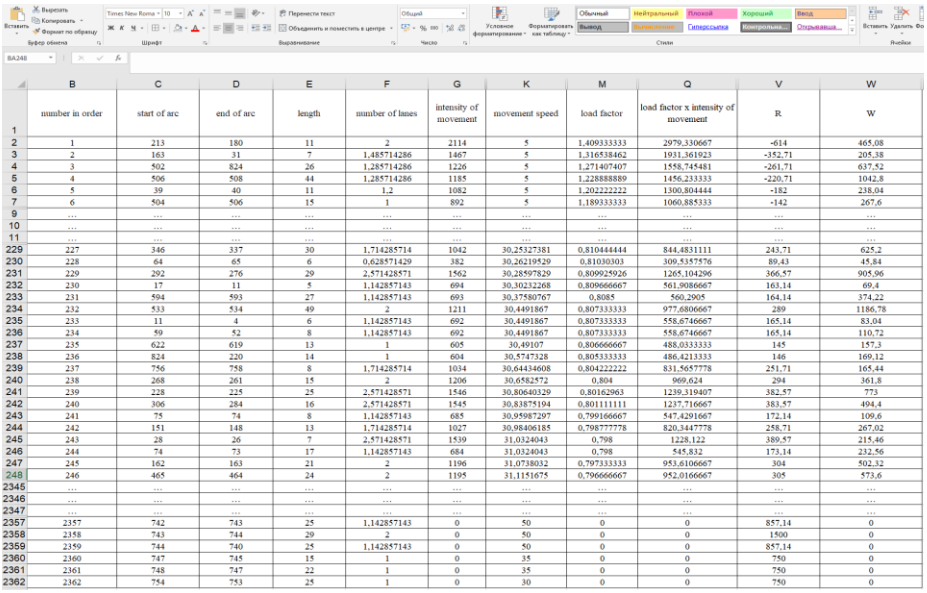
Transport operation (W):

$$W = \sum_{i=1}^{n} N_i \cdot l_i, \tag{6}$$

where l_i – the length of the i-th arc, km.

3. Results

Calculated according to dependencies (4) – (6) the indicators for different motorization levels values are shown in Fig. 2 and Table 1.



	B	C	D	E	F	G	K	M	Q	V	W
1	number in order	start of arc	end of arc	length	number of lanes	intensity of movement	movement speed	load factor	load factor x intensity of movement	R	W
2	1	213	180	11	2	2114	5	1,409333333	2979,330667	-614	465,08
3	2	163	31	7	1,485714286	1467	5	1,316538462	1931,361923	-352,71	205,38
4	3	502	824	26	1,285714286	1226	5	1,271407407	1558,745481	-261,71	637,52
5	4	506	508	44	1,285714286	1185	5	1,228888889	1456,233333	-220,71	1042,8
6	5	39	40	11	1,2	1082	5	1,202222222	1300,804444	-182	238,04
7	6	504	506	15	1	892	5	1,189333333	1060,885333	-142	267,6
9	…	…	…	…	…	…	…	…	…	…	…
10	…	…	…	…	…	…	…	…	…	…	…
11	…	…	…	…	…	…	…	…	…	…	…
229	227	346	337	30	1,714285714	1042	30,25327381	0,810444444	844,4831111	243,71	625,2
230	228	64	65	6	0,628571429	382	30,26219529	0,81030303	309,5357576	89,43	45,84
231	229	292	276	29	2,571428571	1562	30,28597829	0,809925926	1265,104296	366,57	905,96
232	230	17	11	5	1,142857143	694	30,30232268	0,809666667	561,9086667	163,14	69,4
233	231	594	593	27	1,142857143	693	30,37580767	0,8085	560,2905	164,14	374,22
234	232	533	534	49	2	1211	30,4491867	0,807333333	977,6806667	289	1186,78
235	233	11	4	6	1,142857143	692	30,4491867	0,807333333	558,6746667	165,14	83,04
236	234	59	52	8	1,142857143	692	30,4491867	0,807333333	558,6746667	165,14	110,72
237	235	622	619	13	1	605	30,49107	0,806666667	488,0333333	145	157,3
238	236	824	220	14	1	604	30,5747328	0,805333333	486,4213333	146	169,12
239	237	756	758	8	1,714285714	1034	30,64434608	0,804222222	831,5657778	251,71	165,44
240	238	268	261	15	2	1206	30,6582572	0,804	969,624	294	361,8
241	239	228	225	25	2,571428571	1546	30,80640329	0,80162963	1239,319407	382,57	773
242	240	306	284	16	2,571428571	1545	30,83875194	0,801111111	1237,716667	383,57	494,4
243	241	75	74	8	1,142857143	685	30,95987297	0,799166667	547,4291667	172,14	109,6
244	242	151	148	13	1,714285714	1027	30,98406185	0,798777778	820,3447778	258,71	267,02
245	243	28	26	7	2,571428571	1539	31,0324043	0,798	1228,122	389,57	215,46
246	244	74	73	17	1,142857143	684	31,0324043	0,798	545,832	173,14	232,56
247	245	162	163	21	2	1196	31,0738032	0,797333333	953,6106667	304	502,32
248	246	465	464	24	2	1195	31,1151675	0,796666667	952,0166667	305	573,6
2345	…	…	…	…	…	…	…	…	…	…	…
2346	…	…	…	…	…	…	…	…	…	…	…
2347	…	…	…	…	…	…	…	…	…	…	…
2357	2357	742	743	25	1,142857143	0	50	0	0	857,14	0
2358	2358	743	744	29	2	0	50	0	0	1500	0
2359	2359	744	740	25	1,142857143	0	50	0	0	857,14	0
2360	2360	747	745	15	1	0	35	0	0	750	0
2361	2361	748	747	22	1	0	35	0	0	750	0
2362	2362	754	753	25	1	0	30	0	0	750	0

Fig. 2 – Calculation results

According to Ukrainian transport policy, the following types of streets and roads were considered in Kharkiv:

- main streets and roads of the city–wide value of regulated traffic (MSRUV);
- main streets and roads of district significance (MSRDS);
- streets and roads of local importance (SRLI).

Table 1. The values of the indicators being studied for different types of streets and roads

Indicator	Indicator street type (Road)	Motorization level (A), car/1000 inh.				
		152	154	156	158	160
$k_L^{av.weighted}$	MSRUV	0,593	0,602	0,613	0,623	0,631
	MSRDS	0,653	0,658	0,666	0,673	0,682
	SRLI	0,400	0,415	0,431	0,444	0,458
R, car/h	MSRUV	733	720	703	689	676
	MSRDS	672	665	656	646	638
	SRLI	686	682	675	669	664
W, car · km	MSRUV	346262	352143	359739	365893	371732
	MSRDS	164335	168539	173603	178831	183331
	SRLI	26534	26871	28051	28998	30083

According to the results in Table 1 the graphs are designed (Fig. 3-5).

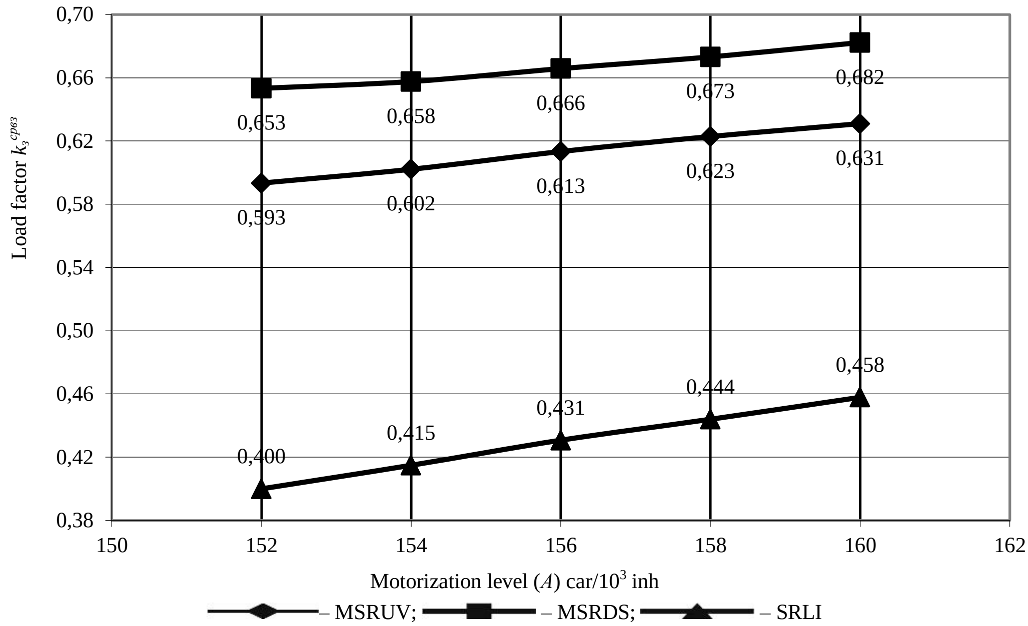


Fig. 3. Dependence of the average weighted value of the load factor ($K_з^{срвз}$) on the motorization level (A) on streets and roads of different types:

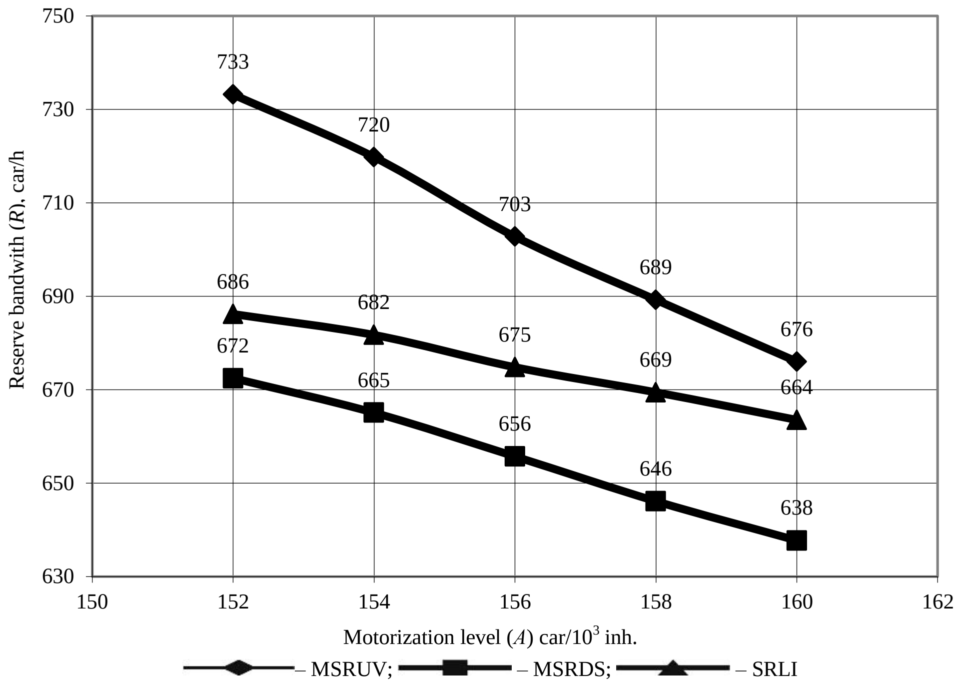


Fig. 4. Dependence of the reserve of the road capacity (R) on the motorization level (A) on streets and roads of different types:

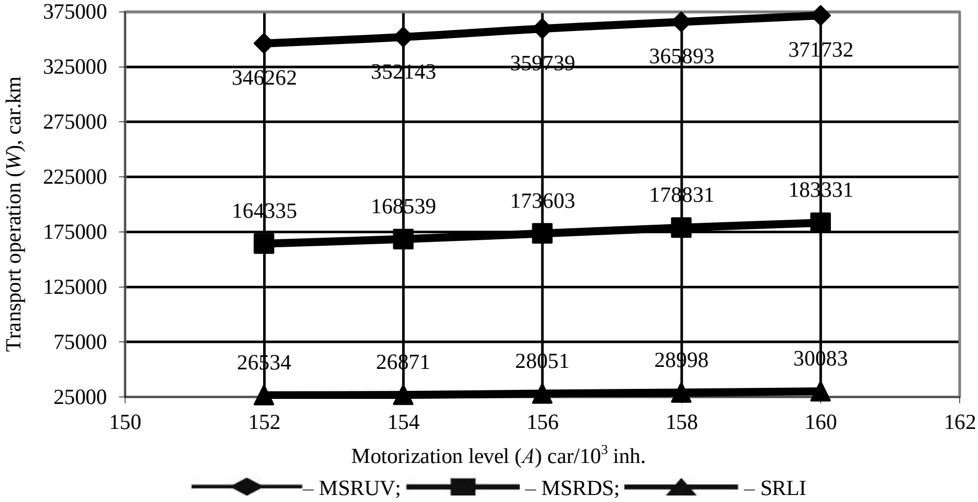


Fig. 5. Dependence of transport operation (W) depending on the motorization level (A) on streets and roads of different types:

From analysis of fig. 3 it is evident that an increase in the motorization level leads to an increase in the traffic load factor. It should be noted the fact of exceeding the value of this indicator on the main roads of district significance over the highways of the urban significance. This is due to the concentration of a large number of vehicles in the "approaches" to the urban highways and with complicated departure on them. For highways of all-city significance with the increase of the motorization level from 152 autos/1000 inh. up to 160 cars/1000 inh. the load factor will increase from 0.593 to 0.631 or 6.4%; for highways of rayon significance – from 0.653 to 0.682 or by 4.4%; for roads of local importance – from 0.4 to 0.458 or by 14.5%.

Analysis of fig. 4 indicates a tendency to decrease the reserve of the road capacity with an increase in the motorization level. Thus, the largest reserve of the road capacity is observed at the urban highways, and the smallest – on the streets and roads of district significance. At the highways of the city significance, with the growth of the motorization level from 152 autos/1000 inh. up to 160 cars/1000 inh. reserve of the road capacity (R) decreases with 733 car/year. to 676 car/hour, which is 7.8%; for streets and roads of local importance – from 686 cars per hour to 664 car/hour, which is 3,2%; for highways of district significance – from 672 cars per hour to 638 cars/hour, which is 5,1%.

Analyzing fig. 5, it should be noted that the increase in the motorization level leads to an increase in Transport activity. The greatest importance of transport operation is on the urban highways, then on district, and then on local streets and roads. With the increase in the motorization level from 152 car/1000 inh. up to 160 cars/1000 inh. transport activity will increase on urban streets with 346262 cars km up to 371732 cars km, which is 7.4%; at the district – from 164335 cars. km to 183331 car. km, which is 11.6%; for local streets and roads – from 26534 cars. km up to 30083 cars km, which is 13.4%.

4. Discussion

Existing approaches to determine the motorization level require additional consideration of population purchasing power indicators of the inhabitants. The impact of the motorization level on urban transport demand was proposed to be estimated by the growth coefficient of traffic volumes in the urban areas. The analysis of the methods of studying the distribution of traffic flows indicates the necessity of applying the gravity method for calculating transport correspondence in the urban transport network. The study of the patterns of urban traffic flow formation was proposed to be carried out by using estimated indicators (load factor for traffic, traffic reserving capacity, transport operation), considering the impact on their motorization level.

This approach to determining the motorization level can be used to calculate the parameters of traffic flows in the transport networks of cities. The offered toolkit allows to estimate influence of motorization level on patterns of transportation flows formation and to plan actions for increase of efficiency of urban transport networks functioning.

5. Conclusions on the research and prospects, further development in this direction

It was found that transport demand is a function of the motorization level. The relationship between them was estimated using the growth factor of traffic volumes. The quantitative parameters of influence of the motorization level on the characteristics of transport demand are obtained. Based on such data, models of transport demand changes in cities were improved as functions of the level of motorization.

Developed models for determining the motorization level, based on statistical data, can determine its impact on the future velocity of traffic. In the models for the first time it is proposed to determine the level of motorization depending on the combination of factors of purchasing power of the population and the number of inhabitants. It has been established that the motorization level in the next five years will reach 160 cars/1000 inhabitants, which in percentage terms will make 5.3% compared to 2020.

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