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The Approach to Determining the Quality Characteristics of Traffic in the Biggest Cities in Ukraine

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Abstract: The transport problems of the biggest cities of Ukraine associated with congestion on transport networks by traffic's overloaded volumes. This caused by increasing number of individual vehicles and, as result, traffic intensity. This process is accompanied by a backlog of transport network from motorization level. The subject of this research is the relationship between quality characteristics of traffic, motorization level and characteristics of transport network. Understanding the mechanism of calculation these characteristics will reduce sharpness of transport problems.

Keywords: Motorization Level, Traffic, Transport Network, Quality Characteristics

1. Introduction

Theproblem of vehicular traffic quality in the critical cities of Ukraine emerges due to transport nets being overloaded by the excess number of personal vehicles. Resolution for this problem must be based on two main constituents – knowledge of mechanisms of motorization level alteration and urban transport net adaption to the vehicular traffic needs.

In the authors' opinion, researches within the scope of this article may be introduced in the form of structure diagram for correlation of vehicular traffic management quality constituents (fig. 1).

Alteration of motorization level in any country of the world depends on the level of social and economic welfare, paying capacity of its population being representative of the opportunity to purchase vehicles. The traffic volume of urban transport net is a direct function of motorization level.

Apart from motorization level, the vehicular traffic management quality is influenced by the transport net characteristics. The urban transport net characteristics comprise its city-building and planning features – density, non-linear communication, traffic capacity etc.

When analyzing correlations between the constituents of the vehicular traffic management quality, the effect of motorization level upon transport net and vice versa is to be emphasized. It is explained by the fact that motorization level alteration gives rise to the net traffic demand and the net itself is to provide sufficient offer in the form of traffic capacity. If imbalance has been observed in this subsystem (the demand exceeds the offer), the qualitative characteristics of vehicular traffic deteriorate.

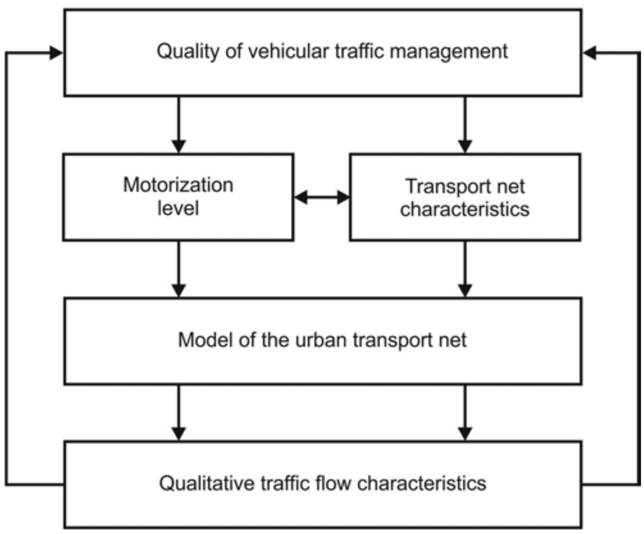

Figure 1. *Structure diagram for correlation of vehicular traffic management quality constituents.*

To assess joint effect of motorization level and transport net characteristics upon the vehicular traffic management quality in the cities, the transport net model enabling to identify the qualitative characteristics of traffic flow characteristics needs to be created.

The relative values obtained as a result of comparison of actually obtained characteristics under the model with the possible characteristics within these traffic conditions shall be deemed to be the qualitative traffic flow characteristics.

2. Calculation of Motorization Level in the Cities

Thestudiesofprinciplesofmotorizationlevelalterationarerefl ectedinarangeofpublications. Thework [1] suggests that the logistical curves, extrapolation methods accounting for one factor – time be used to estimate motorization level. The factor of gross regional product increase as well as the capacity of the urban transport infrastructure has been used to estimate the motorization level of motor cars in the work [2].

The approach suggested in the work [3] in accordance with which motorization level is calculated on account of the value of the average income per capita of population is noteworthy. Nevertheless, the factor of the value of the average income per capita appears to fail to comprehensively take into account the actual purchasing capacity of urban residents. Additionally, the existing approaches to motorization level calculation fail to account for the factor such as changes in urban population size.

In view of problem statement and recent publications analysis, the objective of this research is determination of trends and development of the urban motorization level alteration model. The research has been conductedby the example of amajor city of Ukraine – Kharkiv.

When conducting the research, the approach outlined in the work [4] has been used as a basis. Under this approach, the motorization level is considered as a function of the following factors:

- number of residents;
- purchasing capacity of population;
- time factor.

The purchasing capacity of population is proposed to be assessed on a basis of the ratio of the difference of values of the average salary over the national economy spheres and minimum wage to the average price of motor car.

In general terms, the motorization level alteration model is of the following form:

$$A = f(\Delta, t, N), \quad (1)$$

Where A–motorization level, car/1000 resid.;
Δ - purchasing capacity of population, cars / months;
t - number of the year of observation;
N - number of residents in the city, mln. residents.

When designing the model, the reported statistical data of Kharkiv for 18 years (within the period from 1998 to 2015) have been used. The regression analysis of the statistics hereinabove [5] enabled to calculate parameters of the model. The parameters of the motorization level alteration models were calculatedat the first stage as functions of each of the equation factors (1) separately. These dependencies are shown in the fig. 2-4.

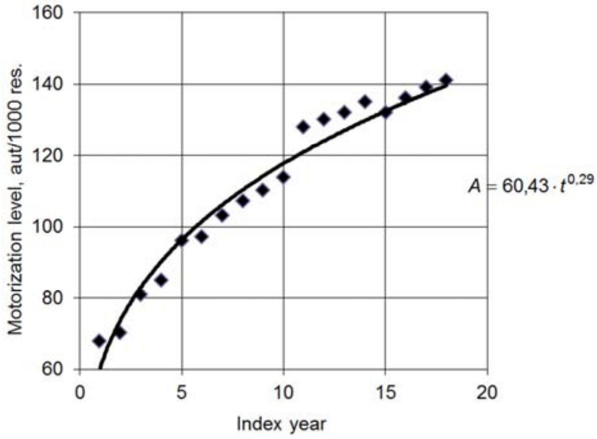

Figure 2. *Motorization level-time dependence.*

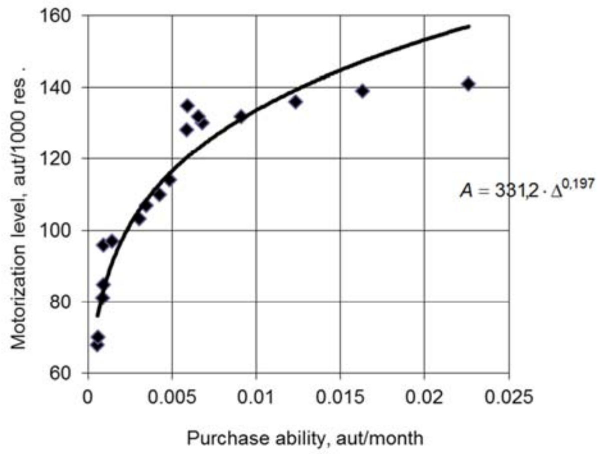

Figure 3. *Motorization level-purchase ability dependence.*

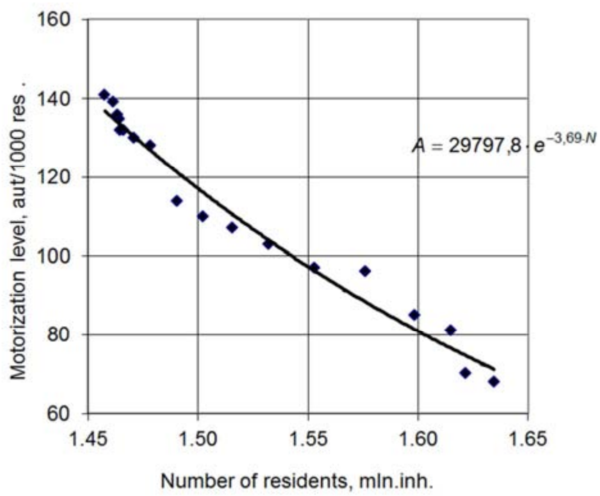

Figure 4. *Motorization level-residents number dependence.*

Characteristics of the one-factor motorization level alteration models are drawn in the Table 1.

Table 1. *Characteristics of the one-factor models.*

Regression equation	Correlation coefficient, %	Standard margin of error, car/1000resid.	Average approximation margin of error, %
1. $A = 60,43 \cdot t^{0,29}$	0,96	3,65	2,86
2. $A = 331,2 \cdot \Delta^{0,197}$	0,92	8,12	6,32
3. $A = 29797,8 \cdot e^{-3,69 \cdot N}$	0,97	3,16	2,43

The data in the Table bear evidence of the relevancy of the obtained one-factor models. The parameters of multiple curvilinear regression equation have been calculated at the second stage:

$$A = 50,62 \cdot t^{0,31} + 42,07 \cdot \Delta^{0,16} \text{-} 0,34 \cdot e^{1,34 \cdot N}, \quad (2)$$

The obtained equation is characterized by the following statistic parameters: correlation coefficient $R^2 = 0,96$; standard margin of error d = 4,68 cars/1000resid; average approximation margin of error $\bar{\varepsilon} = 3,18\%$.

The abovementioned multifactor regression model of motorization level alteration in the city of Kharkiv is relevant and may be used to calculate traffic volume in future.

3. Developmentof the Urban Transport Net Model

The mathematical model relevantly reflecting the specifics of elements functioning for the system “street road net – traffic flows” is to be created to calculate reasonable traffic flow characteristics. The mathematical models are used to solve a wide range of problems regarding transport. They are intended to estimate traffic flows within the nets of known geometry and characteristics with the known location of various units at the territory of the city or urban conglomeration [6, 7]. The models of this type are used to take decisions related to urban development planning, to analyze the consequences of any arrangements with respect to traffic, selection of alternative projects to develop the transport net [6].

Availability of a wide range of factors affecting the system “street road net – traffic flows” as well as the process of their functioning in random environment allows for the choice of the model to be further analyzed. The model typeis determined by the research assignment. When studying the systems depending on the assignment set, two approaches are possible – micro- and microapproach. With the macroapproach, functioning of the system “street road net – traffic flows” is observed in terms of inputs and outputs. We shall take the street and road net parameters as inputs and the traffic flow functioning characteristics as outputs.

The macroapproach to study of the large-scale urban transport system implies macro models creation. They consider the traffic flow as a static phenomenon characterized by general average intensity, velocity and density. At the same time, substantial approximations are used in them and a range of details is disregarded [8-10].

Theprocess of traffic flow formation is a result of functioning of transport systems of the biggest cities [6]. The traffic flow consists of the vehicle communication complex implemented at the same route the formation trends of which follow certain rules and may be formalized.

The necessity of understanding the traffic flow formation trends is urged by implementation of mathematical models when modeling traffic flows. In the practice of traffic flows modeling there are several different approaches to description of the trends of formation thereof.

The traffic flow formation trends based on the macroscopic approach are reflected in the works [6, 8, 9]. This approach is based on the fact that the correlation between the traffic flow characteristics may be established on the basis of experimental data when analyzing marginal conditions as well as on physical analogues [6].

Underthe experimental data, the velocity-density dependence for the one-way traffic flow is represented by V. Greenshields in the following form of linear dependence:

$$v(q) = v_{\max}(1 - \frac{q}{q_{\max}}), \quad (3)$$

where $v_{\max}$ - maximal traffic velocity (velocity of free traffic), km/hr;

q - density,car/km.;

$q_{\max}$ - maximal density, car/ km.

An individual case of the equation is indicative of existence of the instability area at the curves $q(v)$ [6]. The instability area at the main traffic flow diagram assumes traffic in the “start-stop” mode. With this traffic mode, so-called “percussion waves” characterized by the changes in intensity and rate of these changes expansion along the flow, appear. Implementation of this method that moves against the observer enabled Lighthill and Whitham [6] to obtain the correlation between the traffic flow intensity and density in the form of the following formula:

$$v = \frac{N_2 - N_1}{q_2 - q_1}, \quad (4)$$

where N_2, N_1 - Traffic intensity in the area of the first and second observers accordingly , car/hr;

q_2, q_1 - traffic flow density in the area of the first and second observers accordingly, car/km;

The velocity in the equation is normally called a wave velocity [6] or the percussion wave velocity. The percussion wave vector is reversed against the traffic flow velocity vector. In the case when $v > 0$, the percussion wave moves down against the transport net space interval if $v < 0_{up}$ [6-9].

The study of percussion waves formation if a narrow road section is available is of a particular interest. In this context, two cases may be considered – traffic intensity at the main road below the traffic capacity of the narrow road section; traffic intensity at the main road significantly exceeding the traffic capacity of the section of interest.

Employing the analogy with the classical compressed liquid and Euler's equation [9], H. Greenberg obtained the dependence describing the ratio between the traffic flow velocity, density and intensity [6-9]:

$$v(q) = c \ln \frac{q_{\max}}{q}, \quad (5)$$

where c - negative constant with dimension of velocity.

Then, the equationis represented in the form [9]:

$$v(q) = v_{\max} \ln \frac{q_{\max}}{q}, \quad (6)$$

Use of deductive method of model designing under marginal conditions analysis such as $v = v_{\max}$ and $q = 0$ enabled to obtain the following ratio between the principal traffic flow characteristics [9]:

$$N = v \frac{q_{\max}}{2} \ln \frac{v_{\max}}{v}, \quad (7)$$

where N - trafficintensity,car/year.

In accordance with [9], the equation precise the macro ratio between intensity, velocity and density at the flow densities lower than the optimal ones.

With the density exceeding optimal, it is suggested that ordinary dependencies be used that leads to discontinuous form of the surface of the main traffic flow diagram for the established state. This theory transformed for the non loaded flows enables to quantitatively describe sudden changes in the traffic flow state that represent a transition from a relatively free traffic to decelerated traffic with often stops and return motion.

In the works [9] it is suggested that the exponential traffic flow velocity - density dependence be used:

$$v = v_{\max} e^{-2q/q_{\max}}, \quad (8)$$

The mathematical model presented in the works of D. Drake, A. May, also allows to obtain satisfactory results when measuring velocity-density dependence, and may be represented by the following formula:

$$v = v_{\max} e^{-0,5(2q/q_{\max})^2}, \quad (9)$$

The trends considered hereinabove have some restrictions as to the flow velocity-density ratio that is why, when describing the flow formation trends, the second-order hydro-dynamical models based on physical analogues [6, 9] are used. These models-analogues are typical for compressed liquid with singular density as well as for thermal conductivity equations. They enable to describe density alterations in the traffic flow at flow gradient alteration as well as the processes of "jams" formation in traffic flows [9].

The described traffic flow formation trends are simple to use and enable to determine their main characteristics. Additionally, the results obtained in ideal conditions are to be taken as averaged and acceptable for modeling of the large-scope transport net functioning characteristics. Nevertheless, by nature, the traffic flow consists of a bulk of motorcars interacting in the motion process. The traffic flow formation trends in such conditions are described by micromodels.

The simplest mathematical model describing the interaction of two motorcars moving one by one is a so-called simplified dynamic model. It is used to determine the maximally possible flow intensity of one road lane [9]:

$$N_{a\max} = A \frac{v_a}{L_\partial}, \quad (10)$$

where A - dimension coefficient;

v_a - motorcar velocity,

L_∂ - dynamic vehicle gauge, m.

This mathematical model is based on two simplifying assumptions - the velocity of all vehicle units in the flow is similar; transport means are homotypic, i.e. they have equal dynamic gauges. The dynamic gauge L_∂ of the vehicle is calculated as a sum of the vehicle length l_a, safe clearance d and clearance space l_o before the motorcar stopped in front. The clearance space l_o or motor cars ranges within 1-3 m [8].

At that, they are three intrinsically different approaches to calculation of dynamic gauge L_∂ :

A. When calculating minimal theoretical distance, they assume absolutely equal brake properties of a pair of motorcars and take into account only the reaction time of a known driver t_p. Therefore:

$$L_\partial = l_a + v_a t_p + l_o, \quad (11)$$

The equation becomes linear. In this case, possible traffic flow intensity has not limits due to velocity increase. However, it fails to correspond to the real drivers' characteristics and causes overestimation of possible flow intensity. The practical significant increase at high velocity plays a key role here [8].

B. In calculations for "complete safety" they assume the distance d to be equal to the full stopping way of the rear (other) motorcar S_{o2}. Therefore, the dynamic gauge:

$$L_{\partial} = l_a + v_a t_p + \frac{v_a^2}{2 \cdot j_a} + l_o , \quad (12)$$

In this simplified formula there has been no section passed per an hour of delay increase marked off, however, only the recent established delay j_a is taken into account. In this case, the equity turns into a quadratic functions and the intensity has limits at a certain velocity value v_a (traffic flow velocity). Such an approach corresponds more to the requirements of traffic safety guarantee at high velocities (more than 90 km/hr) [8].

C. The most real approach is based on the initial condition that, when calculating the safety distance d, the difference of the motorcar break ways (or of delays) as well as the fact that a "leader" in the breaking process also drives at a distance equal to its break way are to be taken into account [8].

Development of this model has also led to a more complicated dynamic theory of passing after the leader that describes the motion process of a motorcar group when the principal motorcar, i.e. the leader of the group, changes moving velocity. In general terms, the trends of this process lie in the fact that changes in velocity and position of the leader called "stimuli" give rise to a certain reaction expressed in alteration of the known motorcar's acceleration and depending on the driver's response [9].

In the most general terms, this theory may be mathematically expressed by dependence proposed by A. Reshel and L. Pipes [6, 9]:

$$x_{n+1} = x_n + (l_o + t_p \cdot v_n) + l_{n+1} , \quad (13)$$

where l_o - Minimal distance between motorcars;

$t_p \cdot v_n$ - the distance between the motorcars positioned depending on the flow velocity;

l_{n+1} -motorcar length;

n - motorcar'ssequential number.

The differentiating equation has been derived first in terms of time than the differentiating equation of the theory of "passing after the leader" [6, 9]:

$$\frac{dv_n}{dt} = \frac{1}{t_p}(v_{n+1} - v_n) , \quad (14)$$

where $\frac{1}{t_p}$ - proportionality factor(driver's response);

$\frac{dv_n}{dt}$ - rearmotorcar'sacceleration;

v_{n+1} and v_n - velocities of the rear and front motorcars.

The disadvantage of the model hereinabove is the fact that the reaction of the known motorcar depends on the relative motorcars' velocity and does not depend on the distance between them.

As a result, it has been established in the researches [6, 9] that the index of driver's response α is inversely proportional to the distance between the motorcars:

$$\alpha = \frac{v_0}{d} , \quad (15)$$

where v_0 - is a distinctive velocity;

d - distance between the motorcars.

As a result, another equation of the theory of "passing after the leader" has been derived [6, 9]:

$$\frac{dv_n}{dt} = v_o \frac{v_{n+1} - v_n}{l} , \quad (16)$$

The works [6, 9] suggested the equation of the theory of passing after leader in the following form:

$$\dot{x}_{n+1}(t) = \alpha \ln \frac{L(t-\tau)}{l_a} , \quad (17)$$

where α - proportionality constant that has dimensions of velocity, m/s;

L - dynamicgauge, m;

τ - delayeddriver'sreaction;

l_a - length of the calculation motorcar, m.

At the same time, it has been suggested that the differential relation [9] be used to model the dynamics of average velocities when describing unequal situations in the traffic flow. This relation was derived from the microscopic description of certain motorcars' motion in accordance with the model of passing after the leader [8, 9].

The transport net functioning model software is developed to solve a range of interdependent problems of the traffic flow parameters estimation in the city. Each of the software blocks is a separate subprogramme with a set of procedures and functions.

Atthe first stage, the output data entry subprogramme reads the information obtained from three preliminary created output data files. The files contain the data on topological transport net peculiarities. Additionally, the subprogramme sorts out the output information and prepares the data array to work with them further.

At the next stage the matrix of the shortest distance between the transport net nodes is calculated and may be calculated with different methods. Due to the fact that the transport net may comprise hundreds of nodes, the main requirement to the programme is high calculating speed. Therefore, in this case the use of the incompact line length method appears to be practical [6]. The advantage of this method is minimal calculation time and high accuracy. The shortest distance matrix is calculated with due account for the manoeuvre limitations existing within the net. The shortest distance matrix is calculated under one of three criteria of optimization of net functioning:

$$\sum_{i=1}^{m} C_{mpi} \to \min , \sum_{i=1}^{m} L_i \to \min , \sum_{i=1}^{m} T_i \to \min , \qquad (18)$$

where C_{mpi} - transportation costs of use of one transport means of i-net curve ; uah;

m–number of net curves forming the flow route trace from one node to another;

L_i -length of i-net curve, km;

T_i -time of transportation flowalongi-netcurve, hr.

4. Calculation of Qualitative Traffic Flows Characteristics

In order to calculate the qualitative traffic flow characteristics, the following questions must be addressed: how long and within what routes the travel within the transport net will take place. After having addressed these questions, the load of any net elements can be determined. The integral objective of calculation of the traffic flow characteristics is interdistrict communication determination. After that the need to distribute the communication in between the transport net emerges. It means that for every two districts the following is to be accounted for: within what routes the travelwill take place and how many road users will use one or another route. This process will be run in the following sub programme where the communication between the transport net nodes will be calculated [10].

At that, the question of selection of the immediate mathematical model to calculate the inter district communication arises.

The software uses the gravity model of communication prognosticating within the transport net [11, 12]. The output data to calculate the communication matrix are the scopes of the traffic flow formation and intake within the net nodes, node characteristics as well as the results of calculation of the shortest distances matrix.

In general terms, the communication from and to the node j is calculated under the formula:

$$H_{ij} = HO_i \cdot \frac{HP_j \cdot D_{ij} \cdot K_j}{\sum_{t=1}^{n} HP_t \cdot D_{it} \cdot K_t} , \qquad (19)$$

where HO_i - dispatchvolumefromi-node, unit/hr;

HP_j - volume ofarrivalstoj-node, unit/ hr;

D_{ij} - functionofgravitation between i and j nodes;

K_j - trimcoefficient;

n–numberofnodesinthetransportnet.

The gravitation function between the net nodes is calculated under the following formulasdepending on the optimization criterion:

$$D_{ij} = L_{ij}^{-1} , \; D_{ij} = C_{ij}^{-1} , \; D_{ij} = T_{ij}^{-1} , \qquad (20)$$

where L_{ij} – distance between the nodes iand j;

C_{ij} – transportation costs for travel with the transport means between the nodes i and j;

T_{ij} – time of transport means travel between the nodes i and j;

After all the communication has been distributed within the net, the qualitative traffic flow characteristics can be calculated.

The qualitative traffic flow characteristics are calculated on basis of the derived traffic flow intensity and velocity values within the net curves. Using these characteristics, we shall make calculations:

-coefficient of road loaded with flow:

$$k_з = \frac{N_i}{n_i \cdot P_1} , \qquad (21)$$

where N_i -flowintensityat i - net curve, motorcars/hr;

n_i - numberofflowlanesat i -net curves;

P_1 - traffic capacity of one flow lane, motorcars/hr.

- coefficientoftraffic flowvelocitydecrease:

$$K_{vi} = \frac{V_{вi} - V_{фi}}{V_{фi}} , \qquad (22)$$

where $V_{вi}$ - freeflowvelocityat i -й net curve, km/hr;

$V_{фi}$ - actual flow velocity at i - net curve, km/hr.

5. Conclusions

The study concerns the quality of the organization of traffic in significant cities found that there has been overloaded transport networks superfluous volumes of traffic caused by increasing levels of motorization. To address these weaknesses, the technique of estimating level of motorization depending on the combination of various factors. In addition, a model of the functioning of the transport network, including the various functions of gravity between the nodes of the network and the optimization criteria. After assessing the quality characteristics of traffic using prposed model can plan activities to improve traffic conditions in the city's transport network by means of its reconstruction. This may be subject to further studies

References

[1] Siliyanov V. V. Theory of traffic flows in road design and traffic management/ V. V. Siliyanov.-M.: Transport, 1977-303 p.

[2] Bakhirev I. A. Calculated velocities within the street and road net designing in the cities: synopsis of a thesis of the candidate of technical sciences; 05.23.11 / I. A. Bakhirev; [Moscow Automobile and Road Construction Institute]- M., 2008. – 20 p.

[3] Nguyen Thi Hong Diyep. Improvement of design norms of the city streets in Vietnam: synopsis of a thesis of the candidate of technical sciences 05.23.11 / Nguyen ThiHong Diyep; [Moscow Automobile and Road Construction Institute] – M., 2008 – 22 p.

[4] Burko D. L. Approach to prospective motorization level determination in the citites/D. L. Burko//Eastern European journal of advanced technologies. Issue 6/6, 2008 – p 33-36.

[5] Afifi A. Statistic analysis / A. Afifi, C. Eizen. – M.: Mir, 1982.–488 p.

[6] Shvetsov V. I., Aliyev A. S. Mathematical modeling of transport net loading – Editorial URSS, 2003 – 64 p.

[7] Mikhaylov A. Yu., Golovnyh I. M. Current tendencies of street and road net designing and reconstruction in the cities. Novosibirsk: "Nauka", 2004 – 266 p.

[8] Inose H., Hamada T. Vehicular traffic management/ Under the editorship of M. Ya. Blinkin. Translated from English- M.: Transport, 1983-248 p.

[9] Khomiak Ya. V. Vehicular traffic management – Kyiv: Vysh. shkola, 1986 – 271 p.

[10] Anikevich A. A., Gribov A. B., Surin S. S. Shift-day planning of motor lorries work with the help of ECM – M.: Transport, 1976–152 p.

[11] Lobashov A. O., Vu Dyk Min. Methodology of vehicular traffic conduct prognostication in the cities// Bulletin of Kharkiv National Automobile and Highway University – Kharkiv; RIO KHNADU. – 2002.

[12] Lobashov A. O., Burko D. L. Calculation of traffic flow velocity in the cities// Communal urban service. Scientific and technical collected volume. – K.: Tehnika, 2006. – Issue 69 – pp. 202-205.

Biography

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Oleksii Lobashov is currently lecturer of the "Transport Systems and logistics" (TSL) at O. M. Beketov Kharkiv National University Urban Economy(NUUE). In 2011 he defended the Doctoral Thesis in specialty 05.22.01 – "Transport Systems". Subject of Doctoral Thesis: "Theoretical Fundamentals for Generation of Transport Streams in Largest Cities". The thesis work is focused on solving the following task:

- development of a system of mathematical models of dependence of transport stream characteristics upon transport network parameters, which allows to improve functions of transport networks in largest cities.

Dmytro Burko (Candidate of Technical Sciences (PhD), Associate Professor)

Dmytro Burko is currently lecturer of the "Transport System sand logistics"(TSL) at O. M. Beketov Kharkiv National University Urban Economy (NUUE). In2015 he defended theses for academic degree of Candidate of Technical Sciences (PhD) in specialty 05.22.01–"Transport Systems" on subject "Regularities of urban traffic flow formation(for example, the city of Kharkiv)". Dmitro Burko is a lecturer in the following disciplines: "Passenger Traffic", "Service Properties of Transport Facilities". Range of scientific interests: traffic management problems.