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ANALYSIS OF CHANGES IN THE COEFFICIENTS OF TRAFFIC VEHICLES INTENSITY INCREMENT IN TIME FOR THE MOTOR ROADS OF UKRAINE

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Abstract. *The paper presents an analysis of changes in coefficients of traffic vehicles intensity increment for eight major groups of vehicles (cars, light trucks, medium trucks, heavy trucks, medium buses, heavy buses, trucks with trailers and semi-trailers), which were determined experimentally by data from visual metering and automatic meters installed on the state highways for the period 2004-2018 years. The parameters and functions of change in the traffic intensity increment for each of the groups of vehicles were selected.*

Keywords: *The vehicles, reduction factor, intensity increment coefficient.*

Introduction

Analysis of the state-of-the-art.

This article is a continuation of the research published in 2015 [1, 2] and found its application in the regulatory document [3] and in the publications of professional publications [4].

During the research in 2004 - 2018, the collection, processing and analysis of data bases on the network of Ukrainian roads, which were carried out visually by employees of the State Enterprise "Ukrdiprodor" and with the help of automatic traffic volume meters installed on roads of state importance.

Data on the intensity on Ukrainian roads was collected from automatic and visual counting points and entered into the database for the following groups: passenger cars; medium buses; heavy buses; light trucks up to 2.0 tons; medium trucks with capacity (2.1 - 8.0) tons; heavy trucks with capacity over 8 tons; road trains with capacity over 8.0 tons; tractor units with capacity over 8.0 tons; trolleybuses. Data from automatic traffic counters of Marksman type according to EURO-6 classification was also fed into this system.

The relevance of the study is due to the increase in traffic volume *N* and the load capacity of vehicles, which occurred in the last decade (Fig. 1).

Based on the review of studies conducted in our country and abroad, it is necessary to perform the data collection and analysis of intensity changes over time in order to establish the regularities of growth coefficients change for different types of vehicles moving on the roads of state importance in Ukraine.

The purpose of the work is to establish the changes in coefficients of traffic vehicles intensity increment for different types of vehicles moving on the roads of Ukraine.

2010	2015	2020
		
N =6250 cars/day	N =7480 cars/day	N =8399 cars/day
E_r=240 MPa	E_r=272 MPa	E_r=335 MPa

Figure 1. – Illustration of changes in traffic volume and the required modulus of elasticity (E_r) of pavement on the road section M-06 Kyiv-Chop on the km 548 + 140 - km 550 + 280 for 2010 – 2020

Problem Statement.

According to paragraph 6.2.10 of Sectoral Building Norms GBN V.2.3-37641918-559: 2019 "Highways. Road pavement. Designs" the total number of the design load passages (N_{dl}) over the service life of the pavement is determined by the eqn (1):

$$\sum N_{dl} = 0{,}7 \cdot T_{cd} \cdot K_n \cdot K_{sum} \cdot N_{1d}, \quad (1)$$

where T_{cd} – the number of calculated days per year, in accordance with the state of deformability of the structure - taken according to Table 6.4 [6];

K_n -– the coefficient taking into account the probability of deviation of the total movement from the average expected - is taken according to Table 6.5 [6];

K_{sum} – sum coefficient, which is determined by eqn (6.11) [6]:

$$K_{sum} = \frac{q^{T_{sl}} - 1}{q - 1} \quad (2)$$

where q – index of changes in traffic volume (changes according to the law of geometric progression) of a given vehicle type by years (established by the results of technical and economic surveys or other data, can vary from 0.80 to 1.10) at q=1, $K_{sum} = T_{sl}$.

T_{sl} – estimated service life (operation) of the pavement, taken in accordance with the State Building Codes DBN V. 2.3-4: 2015 "Highways. Part I. Design. Part II.

The change in the composition of the traffic flow to the initial year of observation in years was determined by the formula [7]:

$$N_g = \frac{N_i\%}{N_b\%}, \quad (3)$$

where: N_g – coefficients of growth by type of i-x vehicles in relation to the base (initial) year;

$N_i\%$ – the number of i vehicles of the estimated type (passenger cars, buses, trucks, etc.) for the estimated year,%;

N_b – .the number of *i* vehicles of the estimated type (passenger cars, buses, trucks, etc.) in the base (initial) year,%.

According to the data used in the design case, the growth of the actual traffic volume can be approximated by the following dependencies: linear, geometric progression and logistic curve (tab. 1). For large settlements (entrances to Kyiv, Odessa, Dnipropetrovsk, etc.) approximation is performed in geometric progression with annual growth of traffic intensity q = (4 - 12) %. For highways passing close to regional centers, the intensity changes according to the linear law with the coefficient of annual growth of traffic intensity q = (3 - 5) %.

Regularities of actual traffic volume growth

Dependence	Prospective average daily traffic volume, cars / day	Total traffic volume over the service life, cars / day
Linear	$N_l(t)=N_0(1+a\,t)$	$N_\Sigma(t)=T_d\,N_0\,t\,(1+a\,t/2)$
Geometric progression	$N_t=N_0(1+q)^t$	$N_\Sigma(t)=T_d\cdot N_0\cdot\frac{(1+q)^t-1}{q}$
Logistic curve	$N_t=N_0(1+K/(1+b\exp(-ct)))$	$N_\Sigma(t)=T_d\cdot N_0\cdot[t\cdot(1+K)+\frac{K}{c}\cdot\ln(1+b\cdot e^{-c\cdot t})]$

Currently in Ukraine, there is no reliable method of determining this parameter for the traffic flow, which leads to further erroneous calculations used in the design of road pavement.

Research methodology

Beginning from 2004, an automated system for the registration of traffic on the roads of Ukraine has been implemented, which determines the types of vehicles based on the principle of electromagnetic induction, with their subsequent classification - type EURO-6

- passenger cars;
- buses;
- trucks without trailers;
- trucks with trailers;
- trucks with semi-trailers,

This classification is the most appropriate for the analysis of the composition of traffic flow, as it allows taking into account heavy vehicles, which have the most destructive impact on the road structures.

In the period 2004 - 2018, Ukraine used an automated traffic accounting system, which included 229 points and a system for collecting, processing, transmitting and storing information on the traffic volume of vehicles on the roads of state importance. Data collection and subsequent data processing and analysis was carried out by specialists of State Enterprise "Ukrdyprodor".

According to the data of the analysis (Table 2) the results of the change in the traffic volume increment as compared to the previous year on the roads of state importance for the period 2004 - 2018 are given.

With the introduction in 2019 dimension and weight complexes of WIM (Weight in Motion) type on the roads of Ukraine, registration of vehicles is carried out in automatic mode with 19 types of vehicles.

Change in the composition of traffic flow on the roads of state importance of Ukraine (international, national and regional importance) according to the traffic accounting data 2004 – 2018

Significance of the road and year of observation	Passenger cars	Light trucks	Medium trucks	Heavy trucks	Medium buses	Heavy buses	Tractors with semi-trailers	Tractors with trailers	Motorcycles and other vehicles
	Percentage of vehicles in the traffic flow, %								
International									
2005	54,38	14,65	10,36	8,75	3,30	2,56	2,81	3,41	0,01
2006	65,90	9,74	5,08	5,43	2,28	1,63	5,68	4,34	0,02
2007	65,90	9,74	5,08	5,43	2,28	1,63	5,68	4,34	0,02
2008	65,48	10,38	4,09	4,52	2,43	1,22	7,56	4,24	0,07
2010	62,91	11,31	4,34	5,08	2,79	1,34	7,83	4,37	0,02
2011	62,73	11,12	4,54	5,15	2,84	1,38	7,70	4,47	0,02
2012	60,38	10,38	3,65	3,71	1,90	0,60	14,28	5,02	0,00
2013	57,55	15,45	3,25	4,19	2,81	0,83	13,87	2,06	0,00
2014	59,67	13,66	3,43	4,14	2,09	0,90	13,84	2,27	0,00
2015	63,29	7,57	2,78	5,21	2,08	0,38	1,53	16,84	0,32
2016	65,49	3,11	0,88	8,76	3,33	3,94	12,14	2,35	0,00
2017	67,83	8,98	2,78	4,32	1,41	0,77	12,41	1,50	0,00
National									
2006	68,90	8,08	5,03	6,28	3,37	1,74	3,16	3,43	0,01
2007	68,90	8,08	5,03	6,28	3,37	1,74	3,16	3,43	0,01
2008	66,11	11,07	4,65	5,41	2,85	1,33	4,96	3,63	0,02
2010	62,46	12,00	4,69	5,92	2,78	1,20	6,43	4,51	0,00
2011	62,60	11,84	4,67	5,92	2,86	1,22	6,44	4,45	0,00
2012	61,16	11,88	3,59	5,41	1,08	0,44	11,16	5,27	0,00
2013	64,10	17,82	3,69	4,00	3,13	0,70	5,63	0,93	0,00
2014	64,77	13,51	3,30	4,21	2,83	0,46	8,20	2,72	0,00
2015	72,08	7,91	3,81	6,86	3,34	0,49	2,56	1,33	0,05
2016	69,94	3,68	0,98	8,68	3,20	4,01	7,45	2,07	0,00
2017	73,46	9,50	2,92	4,20	1,65	0,40	6,55	1,32	0,00
Regional									
2006	64,83	10,55	5,46	6,19	2,67	2,21	3,60	4,48	0,00
2007	64,91	10,53	5,44	6,18	2,67	2,21	3,59	4,46	0,00
2008	64,60	11,43	5,00	5,49	2,71	1,09	6,20	3,36	0,11
2010	63,91	12,19	4,76	5,81	3,01	1,14	5,53	3,60	0,04
2011	63,14	11,57	4,72	5,40	2,81	1,07	7,40	3,78	0,11
2012	63,07	12,22	5,15	5,15	2,21	0,46	7,87	3,87	0,00
2013	61,48	17,45	4,11	4,87	3,26	0,51	6,71	1,61	0,00
2014	65,88	12,75	3,88	4,55	2,56	0,28	8,03	2,06	0,00
2015	75,86	12,74	3,95	2,75	2,90	0,26	0,79	0,72	0,04
2016	70,52	4,13	1,25	8,36	3,66	3,70	5,78	2,58	0,01
2017	71,30	9,83	3,23	4,43	1,94	0,27	7,32	1,65	0,00

Methods and process of researching the changes in the traffic volume on the roads of Ukraine are presented in the works [1-4] and they have a drawback in the key parameter: the area of the wheel imprint is not fixed and does not allow full performance of calculations of pavement design in the future.

Fig. 2 shows the data on the changes in coefficients of traffic vehicles intensity increment and patterns of their changes for different types of vehicles for the period 2004 – 2018

Figure 2 – Change in traffic volume increment for the period 2004 - 2018: a) passenger cars and volume growth for traffic flow; b) light trucks medium and heavy trucks; c) medium buses (up to 30 passengers) and heavy buses (over 30 passengers) d) trucks with semi-trailers (tractor-trailer) and trucks with trailers

According to the analysis of accounting the traffic volume on the highways of state importance in Ukraine, it was found that the change in traffic volume does not comply with the law of geometric progression, as it is assumed in the design works to date.

Observations have shown that for passenger cars growth factor is a constant value, the growth factor for buses of small and medium-sized vehicles has increased in comparison with 2004 from 1.2 to 1.55, for large buses there is a decrease from 1.00 to 0.58.

The biggest change in the growth of the increment coefficient was observed for truck tractors with semi-trailers from 1.0 to 5.0, i.e. 5.0 times; decrease for trucks with trailers from 1.77 to 0.8, i.e. 2.0 times. There was an increase in the growth coefficients from 1.0 to 1.5 for light trucks and a decrease for medium and heavy trucks from 1.0 to 0.6, i.e., 1.5 times.

The coefficients of change in intensity increment, in general, cannot be approximated by a single dependence for ten years. In an unstable economy they

cannot be predicted with a given reliability. The error between the projected and actual values can be up to (400 - 600)% (Fig. 3). The solution to this issue is to annually determine the intensity and composition of traffic flow on the whole road network in order to obtain reliable data.

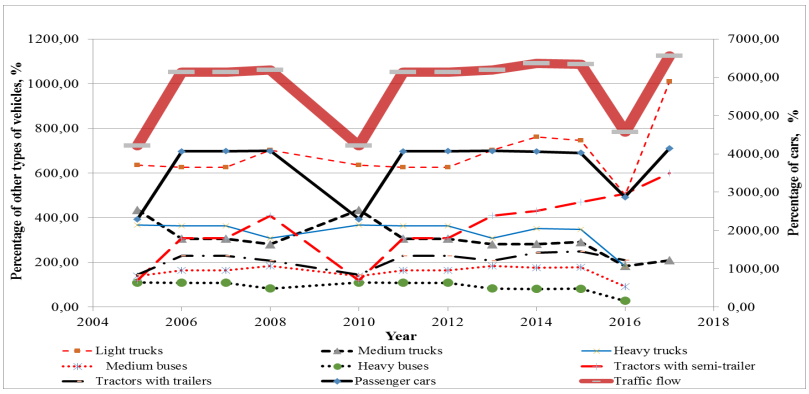
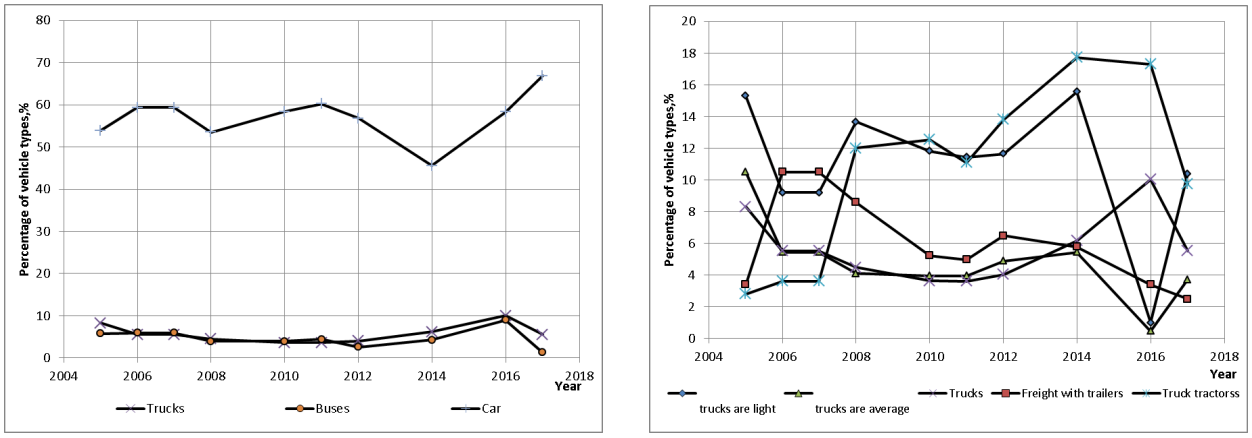


Figure 3 – Change in the percentage of traffic vehicles intensity increment 2004 -2018.

Even greater changes occur on specific roads in the Southern region of Ukraine. For the example, for the road M-14 Odessa - Melitopol - Novoazovsk (Tahanroh direction) for the period 2004 - 2018 an analysis of changes in traffic volume and composition of traffic flow was carried out (Fig. 4).



a) b)

Figure 4 – Change in the composition of passenger cars and buses (a) and different types of trucks % (b) by years on the road M-14 Odessa - Mykolaiv - Novoazovsk (Tahanroh direction) km 94 - km 128

At different accounting points, the structure of the fleet varies heterogeneously and according to different patterns. In large cities the number of passenger cars is growing. The percentage of tractors with semi-trailers is constantly increasing (Fig.4) and is often not systematic. The reasons: the shortcomings of visual methodology of accounting traffic intensity, the complexity of the process of systematic accounting, political and economic instability of the state development, the impact of the occupation of the Autonomous Republic of Crimea and some areas of Ukraine (parts of Donetsk and Luhansk regions).

Fig. 5a - d provides more detailed data on the change in traffic vehicles intensity increment relative to the first year of observation for the selected type of vehicles at

various points of observation.

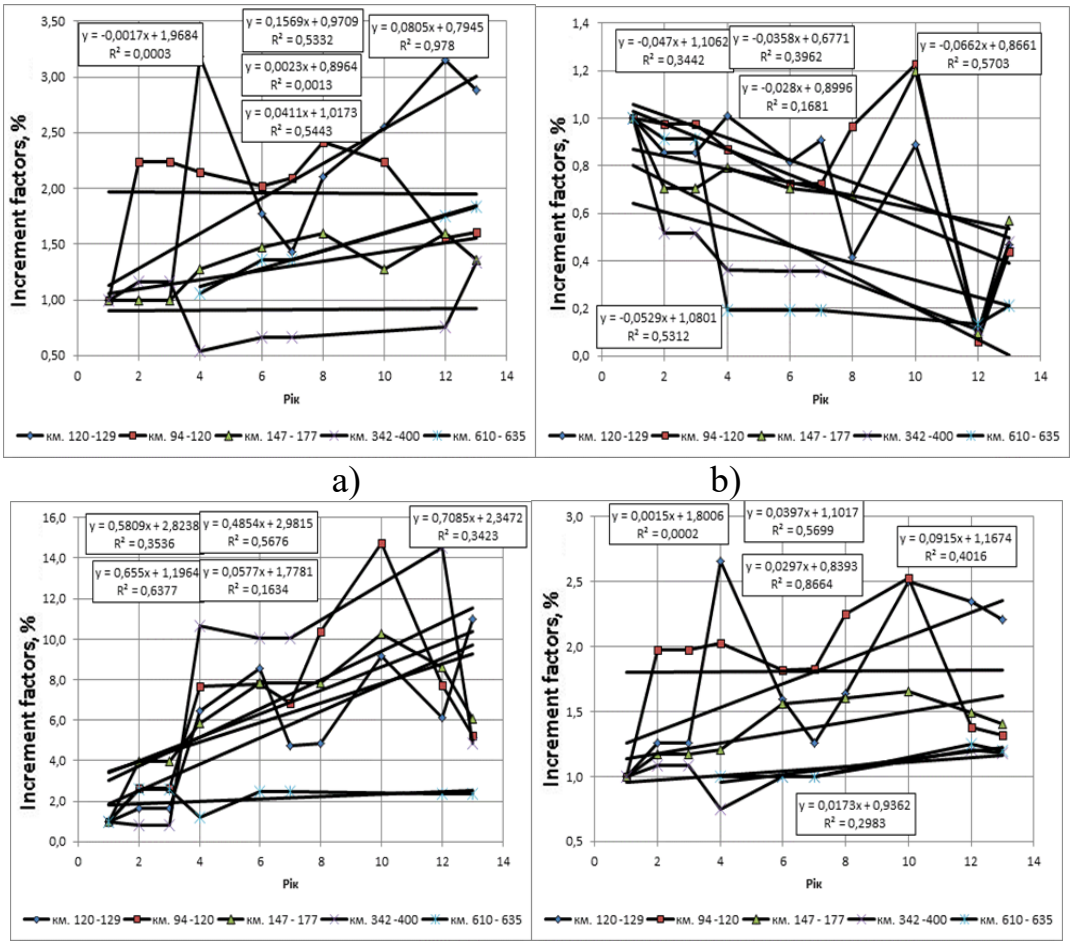


Figure 5 – Change in traffic vehicles intensity increment for the period 2004 - 2018: a) passenger cars; b) medium trucks; c) trucks with semi-trailers (truck tractor) d) total flow of vehicles on the road M-14 Odessa - Mykolaiv - Novoazovsk (Tahanroh direction)

To determine the average daily traffic volume it is more appropriate to use a linear dependence of the following type

$$Nl(t)=N_0 (1+a (t-1)), \quad (4)$$

where: N_0 – average daily summer traffic volume in the first year of operation,

a – annual coefficient of growth of traffic volume.

The greatest changes occurred in the structure of traffic flow, which is associated with a dramatic increase in the number of tractors with semi-trailers, which have the most destructive impact on the road pavement. For trucks with semi-trailers (truck tractors) we observe practically linear dependence of $Kзр=a•t+b$, the increase in traffic volume for the road M-14 Odessa - Mykolaiv - Novoazovsk (Tahanroh direction) with the coefficient of annual increment:

a = 0.484 to 0.655 for the sections of this road km 120 - km 147; km 177 - km 610;

a = 0.708 for the section km 147 - km 177;

from a = 0.057 for the section km 610 - km 635 in the immediate vicinity of the occupied territories (Donetsk and Luhansk).

For practical application, when calculating the long-term traffic volume, it is advisable to use linear regression with the coefficient of increment for tractors with semi-trailers for the road M-14 Odessa - Mykolaiv - Novoazovsk (Tahanroh direction):

a= 0.75 for the sections of this road km 120 - km 147; km 177 - km 610;

a= 0.5 for the section km 147 - km 177;

a= 0.15 for the section km 610 - km 635 in the immediate vicinity of the occupied territories (Donetsk and Luhansk).

Conclusions.

According to the results of the work, it is impossible to determine with high reliability the mathematical regularities that allow predicting the change in the intensity increment and composition of the traffic flow with a given probability, which is necessary when calculating the pavement design for the dynamic action of the load.

On the basis of the obtained data, the method of determining the traffic volume based on the results of short-term observations allow reasonable taking into account temporal factors (hour, day of week, month of measurement) to establish the volume and composition of traffic, with subsequent clarification of parameters, characteristics of traffic flow for the design of road pavement is refined.

The obtained values of changes in the increase in the intensity increment of trucks should be used in:

- design of rigid and non-rigid pavement;
- calculation of bridges and culverts;
- in the selection of locations of weight control points (stationary, WIM and mobile)
- calculation of tolls and determining the level of funding for road facilities;
- development of regulatory documents.

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