ORIGINAL ARTICLE
DOI: https://doi.org/10.30932/1992-3252-2021-19-6-8

World of Transport and Transportation, 2021,
Vol. 19, Iss. 6 (97), pp. 188–193

Features of Methods for Assessing the Long-Term Traffic Intensity in the Design of Toll Roads

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ABSTRACT

Long-term traffic intensity is among core characteristics that determine main parameters while developing projects for construction of new highways. The long-term traffic intensity influences estimated speed, pavement design, total number of traffic lanes, width of traffic lanes and roadsides, longitudinal slope, radii of horizontal curve, transverse slope, radii of convex and concave curves regarding the longitudinal profile, width of median strip, layout of intersection or junction with other roads.

Existing methods for predicting traffic intensity for toll roads are also deterministic and cannot estimate the range of values for the listed indicators. In this regard, the objective of the study is to identify the features, advantages, and disadvantages of existing methods for assessing the long-term traffic intensity for toll roads.

The study considered both traditional, classical methods (extrapolation, historical analysis, approximation) and promising innovative approaches based on the theory of fuzzy logic and neural network modelling.

Keywords: *transport, road design, traffic intensity, toll road, toll highway, traffic stream modelling, transit capacity.*

For citation: *Mikryukov, K. S. Features of Methods for Assessing the Long-Term Traffic Intensity in the Design of Toll Roads. World of Transport and Transportation, 2021, Vol. 19, Iss. 6 (97), pp. 188–193. DOI: https://doi.org/10.30932/1992-3252-2021-19-6-8.*

The text of the article originally written in Russian is published in the first part of the issue.
Текст статьи на русском языке публикуется в первой части данного выпуска.

INTRODUCTION

Traditionally, construction and maintenance of roads is at the expense of the state (central and/or local authorities). Funds for financing roads are mainly formed due to the receipt of tax (excise, local taxes), customs and other (road fees) payments [1]. In the second half of 20^{th} century, the topicality of the issues of the harmful effects of vehicles and massive traffic jams raised in many countries of the world.

Traffic congestion is a global problem that almost every person living in a big city happens to face. This results in wasted time. In addition, rapid development of transport, especially the current unlimited use of private cars, results in serious air pollution and the energy crisis. These problems seriously limit further development of infrastructure and cities around the world. In this regard, today there is an urgent need for development of appropriate highly adaptable public policies and consistent implementation of effective measures that will allow to eliminate above mentioned problems caused by unsustainable traffic systems and will subsequently result in environmentally friendly development of low-carbon and energy-efficient transport systems.

At the first stage of meeting those problems, some countries have started to build toll roads. Toll is one of the effective methods that allows managing traffic demand. It is also widely used as a useful tool to reduce road congestion and pollution [2]. Recent advances in information and communication technology have made it easier to implement a road pricing. There are several well-known examples of successful electronic road pricing around the world, including tolling schemes in California, Singapore, and London, which are based on the calculation of the average attended daily traffic intensity.

A period of 20 years is usually taken as a long-term period. That is, for 20 years, the road should function effectively within the parameters that are determined by the category [type] of the road and that have been set at the stage of its construction [3]. Consequently, the cost of its construction and the efficiency of its operation in the future will depend on reliability of identifying the annual average long-term daily traffic intensity at the design stage of the road.

At the same time, it should be noted that the existing methods for determining the long-term traffic intensity for the purposes of construction of new toll roads differ significantly depending on the specification of the methods that form their basis, consideration of some or other parameters of a highway, measuring instruments used, and the purposes of setting the toll.

Therefore, considering the foregoing, the study of the features, possibilities, constraints and areas of application of methods for assessing the long-term traffic intensity during construction of toll roads is an urgent scientific and technical problem, and the article is devoted to its solution.

The analysis of recent studies and publications indicates that the issues of toll roads have repeatedly become the subject of research by domestic and foreign authors.

The most comprehensive study of this issue was made in the works of V. I. Bryzgalov, M. O. Karpushko [4], I. Gusti Ayu Andani, L. La Paix Puello, Karst T. Geurs [5].

A. V. Vishnevsky, S. S. Igoshin, M. O. Karpushko, I. L. Bartolomey dealt with the issues of optimal design of toll roads from the point of view of sustainable development of territories [6].

The works of V. S. Anderyuk, O. A. Ageeva [1; 7], Yudi Harto Suseno, Muhammad Agung Wibowo, Bagus Hario Setiadji [8] are devoted to forecasting the parameters of traffic streams using analytical methods.

However, despite a wide range of scientific research on the topic, the issues of traffic intensity on the future highway, the algorithm for its calculation and the core impact factors, as well as the adjustment mechanism, considering changes in the socio-economic development of a territory, remain unresolved.

Thus, the *objective* of the study is to improve the accuracy of substantiation of technical parameters and expand approaches to assessing the long-term traffic intensity of toll highways by identifying shortcomings and advantages in existing methods for substantiating the long-term traffic intensity, which do not consider now many factors.

METHODS FOR ASSESSING THE FUTURE TRAFFIC INTENSITY

The intensity is one of the main indicators that characterises the conditions of the stream movement and is determined by the number of vehicles that have crossed the street or road per unit time [8]. One of the features of this indicator is that it changes over time, and this change is stochastic in nature; the obtained intensity values can differ significantly during certain hours of the day, days of the week, months of the year, etc.

If the existing traffic trends continue, the increase in traffic intensity on toll roads will sooner or later reach the road capacity level, which, in turn, will negatively affect traffic conditions, cause lower comfort, congestion, increased danger on the roads, and so on. All these factors harm human health and cause unforeseen costs for the road sector, increasing the energy intensity of roads [9].

Today, assessment of the long-term traffic intensity on toll highways widely applies practical calculation methods, which are divided into several large groups.

The *first group* of methods involves calculations based on the forecasts for socio-economic development of a region where it is planned to build a new toll road. A wide range of various data is considered based on which it is possible to determine the degree of influence of certain factors on traffic intensity and find out whether there is a relationship, and if so, which is its form (direct, inverse, linear or non-linear form) and which equation can describe it, and to what extent the intensity of traffic is subject to fluctuations (changes). These factors include the condition, arrangement and improvement of roads, population residing in the studied area, the structure of the traffic stream, geographic and climatic conditions, the presence of poles of attraction, density of the road network, etc. These methods are based on extrapolation. The accuracy of predicting development of traffic intensity depends on the correctly chosen hypothesis for further changes in the process which is the growth rate.

Graphs built based on traffic accounting data during the observation period often have points with a certain scatter, which allows, when processing data, to apply various extrapolation patterns with almost the same error. As a result, predictive intensity values are calculated [8].

The following hypotheses are the most widespread.

1. The growth of traffic intensity corresponds to a linear relationship:

$$N_t = N_0 (1 + q_t), \quad (1)$$

where N_t – future (calculated) intensity in t years, cars/day;

N_o – intensity (actual) in the year of design, cars/day;

q – dynamics of increase/decrease in intensity in shares of the intensity for the previous year.

2. Increasing traffic growth rates:

$$N_t = N_0 (1 + q_t)t. \quad (2)$$

3. The long-term traffic intensity is expressed by a logistic curve with an initial rapid growth, which eventually turns into a slight increase:

$$N_t = N_0 \left[1 + 0,01 \left(k_1 t + k_2 \sum_{t=1}^{n} t_i^{\frac{1}{3}} \right) \right], \quad (3)$$

where k_1 and k_2 are coefficients obtained experimentally depending on the initial increase in intensity and determined by the expression [11]:

$$k_1 = 6,7–0,3q_n, \quad (4)$$

$$k_2 = 1,3q_n – 6,7. \quad (5)$$

4. The long-term traffic intensity can be determined by a polynomial of the following form:

$$N_t = N_0 + a_t + b_{t2} + c_{t3} + ... + m_{tn}, \quad (6)$$

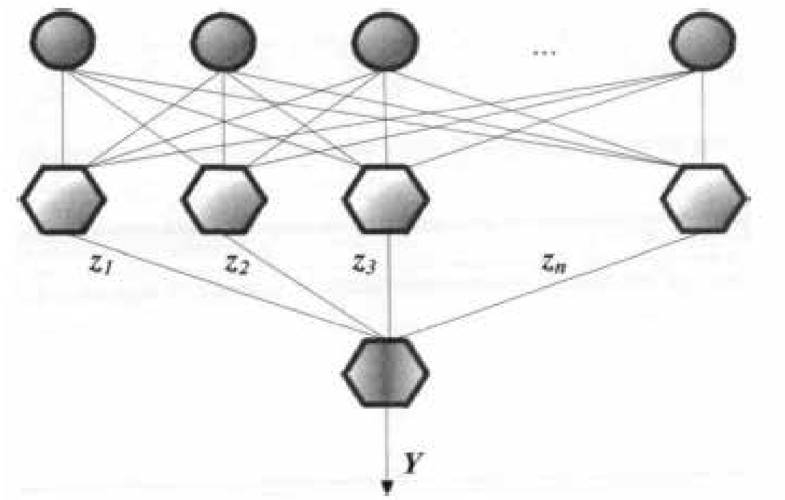
where $a, b, c ...m$ are coefficients obtained experimentally.

In this polynomial, the number of terms in the series depends on the type of curve and traffic intensity data.

The *second group* is based on historical traffic volumes on similar roads, based on which a forecast is made about changes in intensity during the forecasted period. This method allows getting a very average, approximate estimate, which is characterised by a significant level of inaccuracy, so it is advisable to use these methods only at the initial stage of designing the construction of toll roads with further mandatory clarification of the data obtained.

The *third group* consists of methods based on multivariate analysis, but they should be used only for those areas where a wide database on traffic intensity and factors influencing it has been collected.

The use of approximating functions has become quite widespread in foreign practices of estimating traffic intensity. To implement this method, an initial series of static data is required, which is aligned by a graphical-analytical or mathematical selection of an analytical function that makes it possible to approximate the theoretical and statistical data to the maximum extent possible [12]. This group of methods has certain similarities with the calculation of intensity based on historical data, but its undoubted advantage is the ability to use digital data processing, as well as the absence of a «rigidly» a priori



Pic. 1. Rosenblatt's perceptron for predicting the intensity of traffic on a toll highway [performed by the author].

connection of the desired solution with a specific model, which allows the methods to show better results under conditions of uncertainty.

So, measurements are carried out on a similar highway for a limited sample of days, the average value (M) and standard deviation (S) of the daily load during busy hours are calculated. Estimates of the normal and high level of load (L) are carried out according to the formula:

$$L = M + k \cdot S, \quad (7)$$

different k-coefficient values are used for normal and high load levels.

$$S = \left[\frac{1}{n-1} \sum_{i=1}^{n} (X_i - M)^2 \right]^{1/2}, \quad (8)$$

where X_i – time-consistent traffic during busy hours, measured on the i-th day;

$M = \frac{1}{n} \sum_{i=1}^{n} X_i$ – mean sample value;

n – number of days when measurements were taken.

If the measurement period is less than 30 days, the estimate will not be very reliable. In this case, it is advisable to conduct special measurement studies to determine the typical values of the standard deviation (for example, as a function of the sample mean).

Some authors believe that to assess the long-term traffic intensity for toll road construction projects, it is not sufficient to apply only methods based on direct extrapolations, but it is advisable to additionally use the method of expert assessments and the method of neural network modelling [13; 14].

Neural network modelling of the traffic stream intensity depending on the environmental load and the parameters of the designed motor transport infrastructure deserves special attention. In this regard, it becomes necessary to identify key groups in the model with semantic context-dependent relationships, which allows us to divide the model analysis into groups:

• Group No. 1. Analysis of spatial-temporal intensity, this group contains only information about traffic intensity.

• Group No. 2. Spatial intensity analysis, this group has information about traffic density, road service facilities and the road network in the surrounding area.

• Group No. 3. Spatial analysis of environmental impact, this group contains data on possible traffic accidents, technical means of traffic control, traffic stream and information about the road network in the surrounding area.

The solution of the forecasting problem, in each selected group, includes implementation of certain steps, such as initial data processing, selection of a measurement scale, creation of a model for analysis, verification of suitability of the model for the constructed model for predicting traffic intensity on the projected highway. Initial processing includes data normalisation, encoding of non-numeric information, and delinking. The main goal of the initial processing is to maximise the entropy of distribution of data parameters [15]. The highest entropy value allows using the information in the input data set at the limit level, which ultimately has a positive effect on accuracy of neural network models.

Pic. 1 shows a neural network that can be used to assess the future traffic intensity in the process of designing the construction of toll roads.

The objective of the spatiotemporal neural network model is to predict the volume of traffic on a road section based on information about the actual traffic at similar points at a given time. The model will perform the calculation based on the difference of template operations that connect the actual intensity value with the intensity value at a given point in time.

Considering the above, for the synthesis of the forecast, the traffic intensity is formally represented as follows:

$I = \langle \Omega, G, X, Y, U, T, \rho, \gamma, \zeta \rangle$,

where $\Omega = \{\Omega_1, \Omega_2, \ldots, \Omega_{n \times m}\}$ – the range of operating conditions of the highway;

$G = \langle V, (D, W) \rangle$ – a model of intersections, junctions, represented by a graph G in the space R;

$V = \{v_i\}$ – graphic vertices (nodes) corresponding to the nodes of future traffic;

$D \subseteq V \times V$ – a set of diagrams for a road section and road network with weighting coefficients $W = \langle \wedge, P, Z \rangle$ (intensity, speed and structure of traffic on a given road section);

$X = \{X_1, X_2, \ldots, X_n\}$ – a set of properties and determinants that describe the state of the road and take on their own values;

$Y = \{Y_1, Y_2, \ldots, Y_m\}$ – range of initial values (number and types of vehicles, turns, intersections, pedestrian crossings, etc.);

$U = \{U_1, U_2, \ldots, U_t\}$ – the range of possible driving modes on the road;

$T = \{t_1, t_2, \ldots, t_l, \ldots\}$ – discrete or continuous time;

$\rho: X \times U \times T \rightarrow \Omega$ – description of changes in the state of the object in a given state (dynamics of traffic intensity when external parameters change);

$\rho: \Omega \times T \rightarrow Y$ – a conclusion with a description of observations of the dynamics of traffic intensity (estimates, conclusions, etc.);

ζ – external uncontrollable factors influencing intensity changes.

Several technical approaches deserve special attention in the process of analysing methods for assessing the future traffic intensity for projects for construction of toll roads, among which the following can be distinguished:

1. Methods of reducing the coefficients of the theoretical transit capacity, allowing to determine the maximum volume of streams on the road or its individual elements without considering the transit capacity of intersections and junctions. The disadvantage of this method is the inability to determine the intensity of traffic on the road section between intersections and junctions. The discrepancy between the calculated and actual results of calculating the maximum traffic intensity on the road section using these methods is from 200 to 600 vehicles per hour.

2. Methods for determining the maximum traffic intensity based on the functional dependencies within «intensity-speed» traffic stream models. The disadvantage of this method is the lack of consideration of the influence of intersections and junctions on traffic intensity. These methods determine only the highest value

of traffic intensity at an average speed of traffic and with partial consideration of the structure of the traffic stream. The discrepancy between the results obtained is from 200 to 400 vehicles per hour.

3. Methods based on the use of «intensity–speed» functional dependences, obtained based on experimental studies. Also, these methods do not make adjustment regarding intersections and junctions, hence, the discrepancy between the obtained calculation results is within the range from 100 to 300 vehicles per hour.

CONCLUSION

The existing methods for assessing the long-term traffic intensity for projects of construction of toll roads differ significantly from each other. As a rule, the future traffic intensity is determined by extrapolating and approximating the accumulated statistical data. The accuracy of forecasting using these methods depends on the correct choice of hypothesis. Promising methods are those based on the theory of fuzzy logic and neural network modelling since they allow the use of modern methods of highly intelligent analysis based on the methods of arranging and turning qualitative data to a quantitative value.

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Article received 16.04.2021, approved 05.08.2021, accepted 27.10.2021.