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TRAFFIC FORECASTING ON THE CITY ROAD NETWORK TAKING INTO ACCOUNT THE CAPACITY LIMIT

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Abstract. *The purpose* of the paper is to present a model of traffic forecasting on the road section based on a model of the transport system. Traffic forecasting is an integral part of the road design process, from investment to the feasibility study of working documentation. The definition of transportation and distribution of cars by sections is based on a set of interrelated factors. Full and reasonable consideration of these factors for complex road networks is possible only with the help of mathematical models and appropriate programs. The accuracy and consistency of the forecast determine the reliability of almost all the main characteristics of the projected object, from the direction of the route and the location of connection points with existing elements of the road network, ending with specific planning decisions for the road objects. *Subject of research:* a road traffic and a traffic intensity. Knowledge of forecast data on traffic intensity makes it possible to predict the possible mechanisms to solve the above problems. *Methodology:* analysis and research of methods used to predict traffic volumes. The method of extrapolation and the method of using approximating functions. *Goal.* The aim of the work is to compare the forecasting methods used to determine traffic on the road. It is also necessary to show the experience of traffic forecasting on the road network from a European country. *Conclusion.* All methods for predicting the volume and intensity of movement are short-lived, and if some achieve the desired predicted result, it is very vague and needs to be tested with complex and expensive research to determine and process the initial data. To achieve the desired results, it is necessary to apply new methods of forecasting modeling or improvement of already known ones, which would take into account the evolution of the entire transport system and its components. Determining the capacity of highways is necessary perform to identify areas with possible congestion, assessment economy and conditions of movement of vehicles, and also for a choice of methods and means to improve the traffic conditions of all road users.

Key words: traffic forecasting, road traffic, traffic intensity, transport system, road network.

JEL Classification: R41, O18, L90

1. Introduction

The constant growth of traffic causes the relationship of changes in traffic between the key numbers in them. It is not enough to control the knowledge base of the transport system of previous periods and the current state, because you need information about your growth rate for future periods to adequately lay perspective requirements to the road network to ensure its efficient operation. Such information may be obtained by applying forecasting methods.

To forecast and solve transportation problems, it is necessary to know information about the prospects and dynamics of changes in the main indicators of future traffic. In this case, forecasting is a process of predicting the future state of the road network based on the analysis of the existing, as well as a systematic evaluation of information about the qualitative and quantitative characteristics of development in the future. To date, the depth of the forecast usually does not exceed 10-15 years, although transport systems often require 30-40 years. It is also important that the forecast is a value that indicates the probability, and as the forecast period increases, its reliability decreases.

Traffic forecast is a very important element as it determines the demand for transport in the future, in relation to the current state and possible scenarios for the development of the network road. Data obtained from traffic analysis is used not only in the study efficiency of the network enriched with new elements (capacity, transport performance), performance parameters such as travel speed and impact on safety, but also for environmental analyzes and evaluation of the economic efficiency of investments.

Determining the capacity of highways is necessary perform to identify areas with possible congestion, assessment economy and conditions of movement of

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vehicles, and also for a choice of methods and means to improve the traffic conditions of all road users. Ensuring high transport and operational qualities roads and traffic safety on them should be considered as the priority of road organizations.

2. The street and road network

The street and road network is a system of transport and pedestrian connections between the elements of the planning structure of the city and parts of its territory, which is intended for the organization of traffic and pedestrians, laying of utilities and landscaping.

The planning structure of the street and road network is the basis for the planning of the city master plan. The principle of its organization is to achieve compactness and save time on movement.

The boundaries of the street along its width are determined by red lines, which are set by the master plan of the city. Red lines are conditional lines that delimit the territory of existing and projection streets and separate them from other areas of the city.

a) The width of the streets for main streets is:
– citywide value of continuous traffic – 50-90 m;
– citywide value of regulated traffic – 50-80 m;
– district significance 40-50 m;

b) The width for streets of local significance is 15-35 m;

c) Width for streets for settlement and rural streets (roads) – 15-25 m.

The width of streets and roads is determined by calculation depending on the intensity of traffic and pedestrians, a set of cross-sectional elements (carriageways, technical lanes for laying underground communications, sidewalks, greenery, etc.) (Figure 1).

City street elements:
1. Roadway.
2. Sidewalks.
3. Strips of greenery.
4. Distribution lanes separating opposite directions of traffic.
5. Underground engineering networks.
6. Ways of rail (tram) transport.
7. Devices for regulation of movement.
8. Devices for drainage of surface waters.
9. Devices for passenger service.

Planning for the development of the street and road network of cities and settlements, as well as the location of city streets and roads should be carried out based on the urban planning standards, land use and development rules, urban regulations, types of permitted land use and capital construction, urban land plans and based on the location of elements of the planning structure (neighborhoods, other elements).

The street and road network of settlements should be formed in the form of a continuous hierarchically built system of streets, city roads and other elements, taking into account the functional purpose of streets and roads, traffic, bicycle, pedestrian and other traffic, architectural and planning organization and nature of construction.

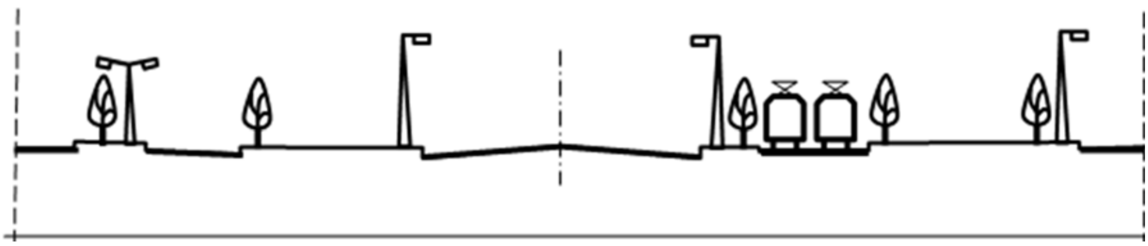

Figure 1. Cross profile of a city street

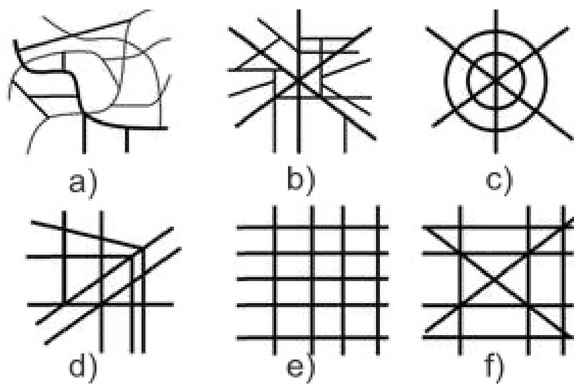

Figure 2. Planning structures of the road network:
a – free scheme; b – radial; c – radial-circular; d – triangular; e – rectangular; f – rectangular-diagonal

The planning structure of cities is based on natural conditions: terrain, the availability of costs and climate.

3. Traffic intensity

Intensity is one of the primary indicators that characterize the conditions of flow and is determined by the number of vehicles that have crossed the street or road per unit time. One of its features is that it is variable over time and this change is stochastic, the studied values of intensities can differ significantly during certain hours of the day, days of the week, months of the year and so on.

While maintaining the existing growth trends, the intensity sooner or later reaches the level of capacity, which in turn will negatively affect traffic conditions: reduced comfort, congestion, increased road hazard, and so on. All these factors harm human health and cause unforeseen costs to the road sector, increasing the energy intensity of streets and roads.

Knowledge of forecast data on traffic intensity makes it possible to prevent and find mechanisms to solve the above problems in advance.

There are several general methodological approaches to forecasting traffic intensity.

Methods based on the use of data on the change in traffic intensity for previous years (extrapolation methods): linear law of growth of traffic intensity, which is described by the following equation (forecasting for up to 5 years)

$$N_t = N_0 * e^{\frac{p}{100} * t},$$

$$N_t = N_0 * \left(\frac{p}{100}\right) t,$$

$$N_t = N_0 * t^a,$$

where a is the exponent for traffic intensity forecasting models that use the logistics curve. Usually these models are described by such a differential equation

$$\frac{dN_{mov}}{dt} = cN_{mov}\,(\text{P-}\,N_{mov}),$$

where N movement for traffic intensity, bus/hour; P is a road capacity, bus/hour.

This model is used for a long-term forecast for a period of 15–25 years.

With the help of these data, it is possible to identify what factors and to what extent they affect the intensity of motion and find out whether there is a connection, and if so, what form (direct, inverse, linear or nonlinear) and what equation can describe it, and to what extent the intensity of movement is prone to fluctuations (changes), regardless of the factors affecting it. Such factors include condition, arrangement and improvement of roads; population in the study area; the composition of the traffic flow; geographical and climatic conditions; the presence of places of attraction; density of the road network, etc. Methods based on multifactor analysis should be used only in those areas of urban space where data on traffic intensity and factors influencing it have been collected.

Another method of forecasting is the use of approximating functions. To implement this method, an initial series of static data is required, which is aligned by a graph-analytical or mathematical selection of the analytical function, which allows to approximate the theoretical and static data as much as possible. The presence of such a function, approximating the value of a static series (data), is a simple mathematical-static model of the rate of motion.

During long-term researches of traffic intensity on the main streets of city importance in cities, the character of change of this indicator is defined. Applying the linear law of intensity growth, exponential equations and multifactor analysis, its predicted values for the future period are calculated.

4. The capacity of the road network

The capacity of the road network is determined by the maximum number of cars passing through the cross-section in a unit of time – an hour.

The capacity of the road network depends on the level of a load of individual highways, the method of traffic regulation at intersections, the proportion of continuous highways, the composition of traffic, the state of coverage and other reasons. However, it should be noted that, considering the movement of cars and assessing the limits of possible flow intensity, we characterize not only them, but also the whole complex of DCRE ("driver-car-road-environment"). This can be explained by the fact that the characteristics of vehicles and the driver can have no less impact on throughput than road parameters. The state of the environment can have a great influence on the actual value of capacity. Bandwidth especially falls in the rain, fog, snow, ice.

The road congestion level is estimated by the ratio of traffic intensity to road capacity. This indicator characterizes the functionality of roads and is complex, as it depends on the parameters of the road, the characteristics of vehicles and the driver, ie is one of the main criteria of a comprehensive system DCRE. When the value is close to one, the density of vehicles increases and their speed decreases.

The operation of the road in the mode of its capacity is inexpedient and unprofitable, because there is a saturation of traffic flow, congestion is formed, the possibility of changing the lane is significantly complicated and the average speed of traffic is reduced.

This method does not analyze individual elements and sections of the highway that can provide the necessary conditions for the movement of vehicles.

It should be noted that the main characteristic of the capacity of the highway is the intersection and adjacency at the same level, as these are the junctions and divisions of traffic flows. These elements of the road are obstacles to traffic, forcing vehicles to slow down or stop completely.

Ensuring high transport and operational qualities of roads and traffic safety on them should be considered as a priority of road organizations. Transport and operational properties of highways are determined by:
– speed and cost of transportation;
– safety and ease of travel on the road;
– bandwidth;
– road load level.

The main transport and operational indicators of roads, city streets, road structures include:
– provided speed and bandwidth;
– continuity, convenience and traffic safety;
– the ability to drive all types of vehicles with the established standard axial load and total weight.

The amount of bandwidth depends on:
– number of lanes;
– speed of vehicles;
– condition of the road surface.

The capacity of the road along its entire length is not constant. Bandwidth can vary under different conditions:
– characteristic complex areas;
– non-compliance with regulatory parameters of the road plan and profile;
– condition of the road surface;
– difficult weather conditions during the year;
– variety of vehicles in the stream.

The capacity of the highway, taking into account the lanes for traffic and the corresponding factor, is determined by the formula:

$$P = P_n * n * K_n ,$$

P_n is a bandwidth of one lane for traffic;
n is a number of lanes;
K_n is a coefficient which depends on lanes.

The capacity of one lane of any category of the road is determined by the formula.

$$P = \frac{S}{L_{min}} ,$$

S is the length of the road traveled by the vehicle in one year, m;
L_{min} is the smallest distance between vehicles, m.

The reference section is a horizontal straight section with a length of at least 1 km without intersections and adjacencies, with a lane width of 3.75 m, fortified roadside, dry and clean and rough surface, visibility of at least 800 m, traffic consists of cars, favorable weather and climatic conditions

5. Example of experience in calculating the forecast of road traffic in Poland

The forecast of the average daily traffic flow until 2020 has been prepared for the sections of the national roads of the Lubelskie region in connection with the Euroregion Bug project. The 1995 traffic was based on data, and then the traffic forecast for 2005 and 2020 was set. We can directly compare forecasts and actual developments in 2005 and 2010.

Based on data from the GPR team in 1995 and previous years, one of the first forecasts was developed and published in 1997 and the results are presented in the table.

Fifteen years later, the same firm conducted a study of the actual volume of rust on Polish roads. The growth rate of traffic in years was:
1.31 between 1995 and 2000.
1.24 between 2000 and 2005
1.19 between 2005 and 2010.
1.16 between 2010 and 2015.

The following is a comparison of 2010 traffic developed by Warsaw Transproject based on GPR research in 1995.

As we can understand, all the above methods of forecasting are not without drawbacks. It seems that the main disadvantage is the difficulty of accurately calibrating the motion model. There is a lack of knowledge about the existing traffic, the behavior of drivers on the roads of vehicles, sources and purposes of traffic, as well as the prospects for development (change) of the road network. The problem is also the difficulty of identifying changes in external conditions (political and economic), which are particularly noticeable in the regions of the Schengen border area.

Table 1
The maximum capacity of roads P max

Number of lanes	Maximum bandwidth Pmax, bus / h (in terms of cars)	
	in both directions	on one lane
Two-lane	2000	-
Three-lane	4000	-
Highways		
Four-lane		2000
Six-lane		2200
Eight-lane		2300

Table 2

Projected movement for 2005-2020

Road number	Section of the road	Average daily traffic of motor vehicles (vehicle / day) in years		
		1 995	2005	2020
17	Kurów – Lublin	11 500	18 000	27 800
	Lublin – Kalinówka	16 700	26 400	36 900
	Kalinówka – Piaski	11 000	18 500	27 300
	Piaski – Krasnystaw	4 300	7 500	11 500
	Krasnystaw – Zamość	5 000	9 100	13 800
	Zamość – Wólka Łabuńska	7 000	12 800	18 100
	Wólka Łabuńska – Tomaszów Lubelski	3 800	7 700	11 300
	Tomaszów Lubelski (przejście)	14 700	24 200	32 700
	Tomaszów Lubelski – Bełżec	5 500	12 500	19 700
	Bełżec – granica państwa	4 000	9 200	15 600
82	Piaski – Biskupice	4 900	9 200	14 300
	Biskupice – Marynin	3 600	7 200	11 000
	Marynin – Chełm	4 200	8 500	13 600
	Chełm – granica państwa	2 800	6 500	11 200
	Łoniów – Nagnajów	5 200	8 600	12 800
	Nagnajów – Nowa dęba	4 200	7 400	11 200
9	Łoniów – Nagnajów	5 200	8 600	12 800
	Nagnajów – Nowa dęba	4 200	7 400	11 200
19	Niemce – Lublin	8 400	12 300	16 800
	Lublin – Kraśnik	6 500	9 900	14 000
	Kraśnik – Janów Lubelski	4 500	6 500	9 800
	Janów Lubelski – Nisko	2 900	4 300	6 500
	Nisko – Jeżowe	2 700	4 000	6 000
44	Puławy – Końskowola	6 600	10 600	15 100
	Końskowola – Kurów	5 200	8 400	12 100
74	Maruszów – Annopol	3 700	6 000	8 600
	Annopol – Kraśnik	4 300	7 000	10 100
83	Sawin – Chełm	2100	3 200	4 400
	Chełm – Rejowiec	2 300	3 600	5 400
	Rejowiec – Krasnystaw	3 300	5 100	6 800
84	Tarnobrzeg – Stalowa Wola	2 500	3 800	6 400
	Stalowa Wola – Nisko	9 000	12 100	16 000
86	Janów Lubelski – Frampol	1 300	1 800	2 400

6. Conclusions

The article presents a model of traffic forecasting on the road section based on the transport system. Traffic forecasting is an integral part of the road design process, from investment to the feasibility study of working documentation. The definition of transportation and distribution of cars by sections is based on a set of interrelated factors. Full and reasonable consideration of these factors for complex road networks is possible only with the help of mathematical models and appropriate programs. The accuracy and consistency of the forecast determines the reliability of almost all the main characteristics of the projected object, from the direction of the route and the location of connection points with existing elements of the road network, ending with specific planning decisions for the road objects. Traffic forecasting determines the demand for transport in the future, in relation to the current state and possible scenarios for the development of the network road. Data obtained from traffic analysis is used not only in the study efficiency of the network enriched with new elements (capacity, transport performance), performance parameters such as travel speed and impact on safety, but also for environmental analyzes and evaluation of the economic efficiency of investments.

Today, all methods for predicting traffic intensity are short-lived, and if some achieve the desired predicted result, it is very vague and requires testing with complex and expensive research to determine and process the initial data. To achieve the desired results, it is necessary to apply new methods of forecasting modeling or improvement of already known ones, which would take into account the evolution of the entire transport system and its components.

We can assume conclusions about the forecasting of traffic volumes of European countries, that the

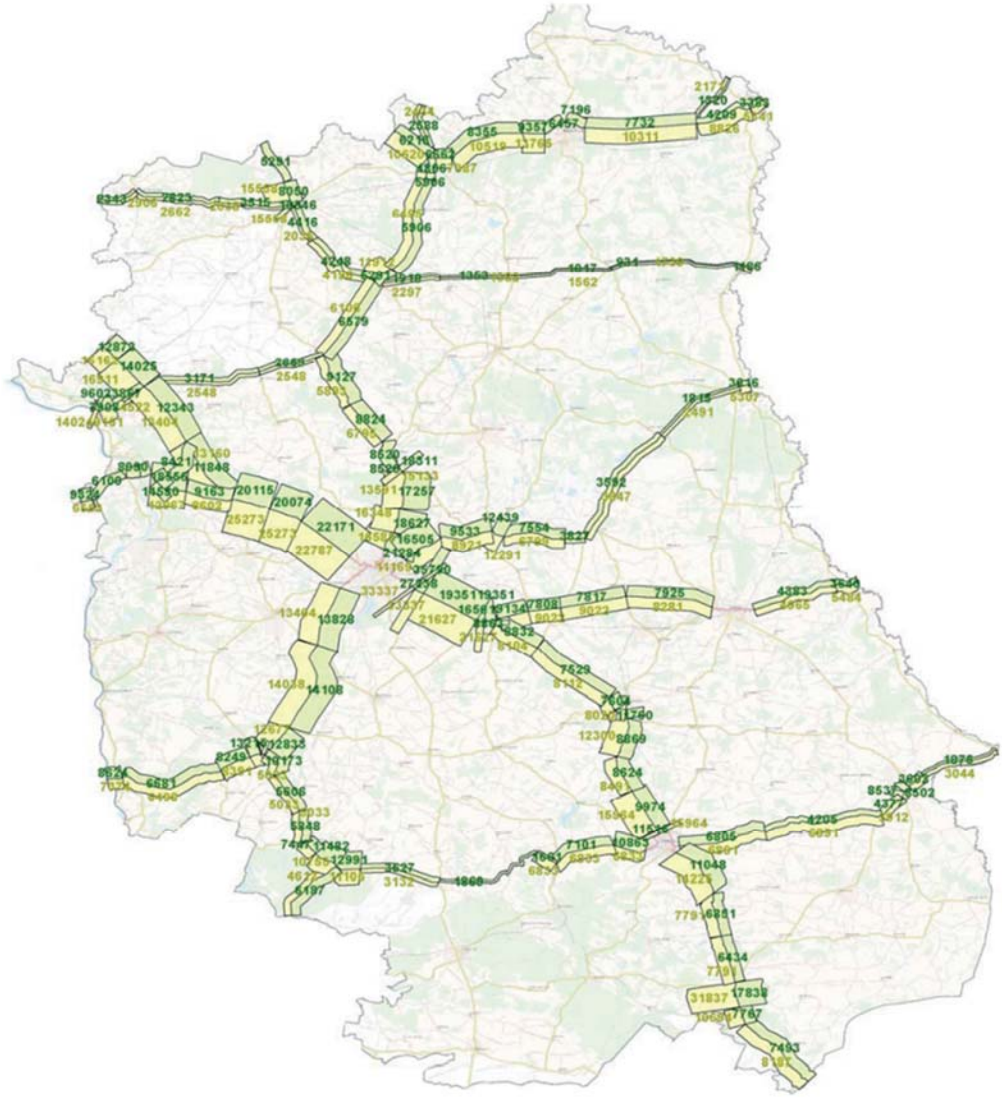

Figure 3. Comparison of total traffic according to data from the General Traffic Measurement from 2010 (green) and the forecast data developed by Warsaw Transprojekt based on GTM in 1995 for the year 2010

accuracy of forecasts is affected not only by the correct application of new modeling methods, the correctness of mathematical calculations, road conditions or traffic intensity. The problem may also be the difficulty of identifying changes in external conditions: political and economic.

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