Development of a graphical method for choosing the optimal mode of traffic light

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Abstract. Changing the transportation infrastructure for improving the main characteristics of the transportation flow is the key problem in transportation planning, therefore the main question lies in the ability to plan the change of the main indicators for the long term. In this investigation, an analysis of the city’s population has been performed and the most difficult transportation segment has been identified. During its identification, the main characteristics of the transportation flow have been established. For the evaluation of these characteristics until 2025, an analysis of the available methods of establishing changes in their values has been conducted. During the analysis of the above mentioned methods of evaluation of the change in intensity, based on the method of extrapolation, three scenarios of the development of the transportation system have been identified. It has been established that the most favorable method of controlling the transportation flow in the entrance to the city is the long term control of the traffic system. For the first time, with the help of the authors, based on the investigations of foreign scientists and the mathematical analysis of the changes in intensiveness on the main routes of the given road, the method of graphically choosing the required control plan has been put forward. The effectiveness of said organization scheme of the transportation system has been rated in the Transyt-14 program, with the analysis of changes in the main characteristics of the transportation flow.

1. Introduction

The experience of using regulated schemes of traffic management today shows its effectiveness. Earlier in the construction of these schemes of road traffic organization, due attention was paid to how this innovation will tell on connecting sites, as a result, this leads to a non-rational use of the road network and the emergence of transport problems. So, for example, in the construction of a large-scale decoupling in neighboring areas, bottlenecks (a bottleneck) often appeared, which led to the fact that the new traffic scheme did not function effectively, and there were steep situations at the entrances. In addition, most schemes were not designed for a long-term period, but acted and could solve the transport problem for a specific period, eventually leading to the fact that after a certain period of time they were not effective. The only measure in which it is possible to avoid the occurrence of a "bottleneck" is the effective use of the duration of the control cycle.

In developed foreign countries, this problem began to be solved as far back as the 1990s, at the legislative level, and in 1991 the Institute of Transport Engineers developed a document on the
planning and assessment of the impact of traffic volume, which is used in the development and evaluation of new traffic control schemes [1]. Teodor [2] consider this problem and talk about an integrated approach to the construction of new facilities, considering seven criteria for analyzing the impact of urban traffic.

In the Russian Federation, the need for an integrated approach to the organization of road traffic came only now and, by analogy with foreign countries, the beginning of this approach is reflected in the legislative level [3]. This document reflects the basic requirements for the development of integrated schemes for organizing traffic, and also defines the duration of the proposed activities - a long-term period of 15 years. Realization of the requirements of this normative document will allow estimating the change in traffic volumes during the development of new ways of managing them, for example, in the construction of new interchanges.

2. Analysis of the research object

Proceeding from this, it is necessary to give due attention to the organization of traffic. The feeding node at the entrance to the urban settlement is the circular inter-section of Shchors st.-Vatutin ave. For further investigation, this intersection is referred to as node 1. During field studies of this node 1 it was determined that the main traffic congestion is observed in the morning and in the evening, which are called peak periods. This phenomenon is explained by the employment of the population and movement to the place of work. Based on the result of the survey, the values of the intensity of the traffic flow along the main directions in the morning and evening hours of the peak were established.

Based on the obtained intensity data, simulated motion was simulated in the Aimsun software product at the crossroads under consideration; during the simulation the main characteristics of the traffic flow were obtained (Table 1).

| Table 1. The main characteristics of the traffic flow at the intersection of Shchors st. - Vatutin ave. |
|---------------------------------------------------------------|
| **Main characteristics of the traffic flow** | **Morning** | **Evening** |
| Delay time, s/km. | 122.91 | 280.79 |
| Traffic flow average speed, km/h. | 25 | 17 |
| The number of vehicles that passed the intersection, vehicles/h. | 3982 | 4202 |

Based on the results of the survey, the main characteristics of the traffic flow of the feeding unit to the urban settlement were determined, it was established that traffic on this site when entering and leaving the urban settlement is difficult, especially in the morning and in the evening, the level of load on the result of the survey at these intervals, Due to the high intensity of the traffic flow is approaching 1, in connection with which there are harsh situations. Due to the fact that the urban settlement is actively developing, construction of residential complexes is underway, the population is increasing every year, in the future, an increase in traffic will lead to a "bottleneck" when entering the urban settlement, which may lead to a number of problems in the future. In order to improve the organization of the movement, it is necessary to develop an approach to assessing the transport situation in the long term, to implement this approach, an analysis of existing methods for predicting the intensity of the traffic flow is carried out.

3. Research on methods for predicting traffic intensity

The selection of scientific sources of foreign and domestic scientists shows that today the issues of forecasting are given special attention. There are a large number of stud-ies of various methods that allow an estimate of the change in traffic intensity for a long-term period [4]. With the purpose of developing an integrated approach to the organization of road traffic on the investigated highway, analysis of these methods has been carried out.

Studies performed by Hashem [5] using the example of traffic volume forecasting for the example of rural roads in Jordan showed that based on the multivariate regression analysis, it is possible to use the linear prediction model most accurately for the aggregate population data, type of road, building
size, but for the research object this model is inappropriate. Due to the fact that the volume of traffic cannot be described by a linear forecast, because the increase in traffic does not always occur on a linear basis, quite often there are changes in intensity. Dixon, in his study [6] in detail analyzes the consequences of an incorrect forecast of traffic growth, confirming the expediency of using the forecasting method, especially when developing complex schemes of organizing traffic for the long-term period.

Studies carried out at the University of Indonesia [7] showed that the most accurate forecast can be obtained using a geographic information system (GIS), but the complexity of using data within the framework of the research being carried out is that these systems have not yet been fully implemented at the research site and it is not possible to determine the accuracy of the transmitted data when using such systems.

According to Dinges [8] when predicting the magnitude of the intensity, extrapolation methods were most widely used, namely two methods related to this group:

1. Simple moving average method.
2. Weighted Moving Average Method.

4. Creating a graphical method of a needed plan of control

To increase efficiency of car flow intensity calculations on all routes we need to find out the dependence of each route from the most intense one. Let’s approximate previously received data in a parametrical form:

\[ N_{dir} = f(N_{tot}, \tau) \]  

\( N_{dir} \) – intensity of vehicles in the direction; \( N_{tot} \) – total traffic flow intensity; \( \tau \) – time value.

At the initial stage is the analysis of dependence of intensity of the movement on each section and the intensity of the movement which is a part of the general intensity in section, carrying out a certain maneuvering on crossing.

Dependences of intensity indicators of the movement in each of the directions:

\[ f(\tau; n) = a + \frac{c}{\tau} + bn + \frac{d}{\tau^n} + en^2 + \frac{f}{\tau^n} + \frac{g}{n^3} + \frac{h}{\tau^n} \]  

\( \tau \) – time value; \( n \) – intensity of car flow 1; \( a = 804.97; b = -1131.38; c = 0.24; d = 104.42; e = -0.0008; f = 1.72; g = 16.01; i = -0.0003; j = -0.18; R^2 = 0.97.\)

As a result of mathematical analysis of possible functions describing the intensity distribution in the directions determined the most accurate feature, using which it is possible to determine the intensity in the directions depending on the General flow of traffic. The use of this feature is confirmed by the high values of the coefficients \( R^2 \) and \( R^2 \) adj and low values of the coefficients AIC and Schwartz identified for each function using lowering the input parameters [9].

During the mathematical analysis and determination of dependence of movement intensity on the directions on the general intensity of crossing functional dependences which accuracy is confirmed by high value of coefficient of determination that have been established. Values of the coefficients which are a part of each equation are presented in Table 2.

| Coefficient | Direction 1 | Direction 2 | Direction 3 | Direction 4 |
|-------------|-------------|-------------|-------------|-------------|
| \( R^2 \)   | 0.97        | 0.97        | 0.97        | 0.97        |
| \( R^2_{adj} \) | 0.865      | 0.865      | 0.865      | 0.865      |
| AIC         | 2.781       | 2.781       | 2.781       | 2.781       |
| Schwartz    | 2.441       | 2.441       | 2.441       | 2.441       |

In a process the mathematical analysis it is established that differences of intensity on various directions exert impact on the modes of the movement on other directions that is confirmed by certain functional dependences [10]. To improve the quality of traffic on the junction, it is proposed to introduce traffic light control, the main issue is the choice of the appropriate cycle duration time for various intensity changes taking into account the long-term period of operation. To determine the
appropriate management mode, based on the analysis of the scientific literature [11], the authors developed a graphical method for determining the appropriate traffic control plan, depending on the intensity of the traffic in the main and most loaded directions.

After the conducted natural researches and improvement of a way of the organization of the movement on the analyzed knot, it is established that the most preferable scheme of management will be input of traffic light management. When calculating the regularity in determination of duration of each of regulation phases which speaks about not expediency of use for control the traffic lights of intensity in all directions of the movement is revealed. It is enough to use one most loaded direction for each phase, receiving result similar to classical definition of a cycle of regulation in all directions.

\[ T_c = T_{c(max)} \]  \hspace{1cm} (3)

\( T_c \) - the cycle duration determined taking into account all directions of the movement in each of regulation phases, sec; \( T_{c(max)} \) - the cycle duration determined taking into account most loaded direction of the movement in each of regulation phases, sec.

The received regularity allows to construct the count for definition of a necessary operating mode of a traffic light object depending on change of intensity in the most loaded direction in each phase of regulation. In mind the most loaded knot we will consider application of the offered model.

The main source of obtaining information on the considered object is continuous monitoring of traffic flow, in this regard establishment of the detector of transport will allow to obtain data on the volume of the movement on the most loaded directions. The offered regulation of a hub 1 happens in 3 phases therefore the count for this site will be under construction on 3 axes, to have a 3-dimensional appearance and the choice of optimum control mode will be carried out in the 1st most loaded direction for each phase of regulation (see Fig. 1).

**Figure 1.** A graph for operation mode determination of traffic lights at the junction 1: where 1 - the mode 1 usage area; 2 – the mode 2 usage area; 3 – the mode 3 usage area; 4 – the mode 4 usage area; 5 – the mode 5 usage area; 6 - the mode 6 usage area; 7 - the area in which it is not advisable to use traffic light control; 8 - area requires further calculations.

During a research, it has been established that the maximum value of size of intensity in the most loaded direction in each phase of regulation exerts impact on control mode of the traffic light. For definition of the optimum mode calculation of necessary duration of a cycle for each value intensity in the direction is made, it is established that there are areas at which use of one control mode is possible.

At the study intersection management has been installed in three phases, according to the result of calculation of the required plan offices using graphical method determined that for each phase regulation of the main settlement is one of the most intensive direction, in order to determine the appropriate management plan, it is sufficient to know the maximum intensity value in each phase of regulation. Therefore, to control three-phase is necessary to determine the three most loaded directions:

\[ \begin{align*} X = (x, y, z) & \overset{\text{max}}{\rightarrow} \text{mode[n]} \end{align*} \]  \hspace{1cm} (4)

\( X \) - the maximum intensity in the direction in the first phase of regulation, un/h; \( Y \) - the maximum intensity in the direction in the second phase of regulation, un/h; \( Z \) - the maximum intensity in the
direction in the third phase of regulation, \(un/h\); \(n\) – number control mode (1…6).

At creation of the graph (see Ошибка! Источник ссылки не найден.), the area 7 at which it isn't expedient to use a traffic light object on the considered crossing has been revealed. The remained area 8 if necessary is subject to further calculations. But today there is no need in this action since during the natural researches of crossing, any of the directions had no distributions of intensity getting in remained not counted area.

By result of modeling of the existing situation and the offered way of management – traffic light regulation taking into account the offered graphic method improvement of the main characteristics of traffic flow, but the main question of long term of functioning of the offered method of management and a way of the choice of the necessary mode is established. Using a graphic method of the choice of necessary control mode in the Transyt 14 software product the analysis of the existing situation at the explored intersection with use of traffic light management in three phases and application of a graphic method of the choice of control mode (Table 3).

| Time period | Fuel consumption at cruising rates (liters per hour) | Fuel consumption as a result of the delay (liters per hour) | Fuel consumption as a result of stops (liters per hour) | Total fuel consumption (liters per hour) |
|-------------|---------------------------------------------------|------------------------------------------------------|------------------------------------------------------|----------------------------------------|
| 08:00-09:00 (the existing regime) | 260,99 | 134,29 | 130,34 | 525,62 |
| 08:00-09:00 (the proposed regime) | 210,99 | 121,02 | 109,15 | 495,75 |

The comparative analysis on change of the main characteristics of traffic flow has been made for the existing and offered scheme of the organization of traffic. On crossing taking into account growth of automobilization decrease in size of a delay of vehicles will be observed, so at the minimum scenario of development use of the offered scheme with use of traffic light regulation on crossing of Shchors St. – Vatutin Ave. delay size for morning rush hour on average will decrease by 27,91%. At the existing intensity of traffic, the delay of vehicles will decrease by 28,45%, at the minimum scenario development of level of automobilization for 61,51%, at an average for 32,31%, but at maximum, this size will increase by 10,62%.

5. Conclusion
In the course of the study, the author's team carried out an analysis of the urban settlement of the urban agglomeration, which is actively developing. Annual population growth and development of the existing territory have an impact on the transport network. Taking into account the analysis of the transport network of the investigated object, it is established that when entering the urban settlement, due to the high load, a "bottleneck" is formed. Based on the result of the analysis of the transport system, the most stressed intersection was determined, its full-scale study was performed and it was determined that the level of its loading, especially at peak periods, is close to 1, therefore, the main characteristics of the transportation flow are significantly reduced, which is expressed in the low speed of communication and the occurrence of long delays At the intersection, which together reduces the available mobility of the population.

As a result of the analysis, the author's team proposed the use of a long forecast for the development of the transport network, therefore, based on the analysis of existing forecast methods, the main scenarios for the development of the transport network (minimum, medium and maximum) are determined using the extrapolation method. With the purpose of reducing the load on the transport network and localizing the "bottleneck" section, the author's team proposed the use of traffic light controls, but the main question on determining the required cycle time is open, based on the analysis of the scientific literature, the author's team proposed the use of a graphic method for selecting the
required signal duration. Having performed an analysis of the change in the intensity value, a functional dependence is established which shows that the magnitude of the intensity along the main feeding directions is distributed according to a definite function that has its own mathematical description. The use of the obtained perspective change in the amount of traffic allowed us to determine the areas of use of different control regimes based on data on one of the most stressed directions in the control phase, which in the long run is allowed to improve the main characteristics of the transportation flow. So, based on the analysis of the main characteristics of the transportation flow in the long term, it is possible to reduce the load on the road network, due to the rational management of traffic flows.

6. Acknowledgments

The article was prepared within development program of the Flagship Regional University on the basis of Belgorod State Technological University named after V.G. Shoukhov, using equipment of High Technology Center at BSTU named after V.G. Shukhov.

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