Local adaptive road control crossroads

A S Kashtalinsky, E V Parsaev and I A Teterina*
Siberian State Automobile and Highway University (SibADI), 644080, Omsk, Mira 5

*lateterina@mail.ru

Abstract. Exploring the properties of traffic flow, collecting and processing statistics on the marker indicators and criteria that characterize these properties is an important task on the road to the implementation of adaptive and intelligent traffic management systems in cities. The article provides an overview of the methods and indicators that allow forming a theoretical basis on the patterns of movement of transport on sections of the street and road network. This base is the source of the initial information for the introduction of adaptive control systems at isolated crossroads in urban environments.

1. Introduction
Traffic flow (TF) in urban environments has a number of specific properties, reflecting its behavior as a system. The fundamental properties in the organization of traffic management are unevenness, stationary, dynamism and inertia.

A characteristic that reflects the manifestation of these properties is the intensity of the traffic flow. Permanent accounting of the properties of traffic flow is possible when organizing adaptive control on the elements of the street and road network (SRN) of cities. In this case, information about traffic intensity is collected using transport detectors and transmitted to the control center in real time. The practice of using such feedback control systems shows its effectiveness, and the issues of their development are quite promising in order to reduce transport delays and improve road safety in urban settings.

Therefore, the aim of this study is to identify dependencies characterizing the properties of traffic flow, based on the study of traffic intensity on the city highway and aimed at developing a theoretical basis for the implementation of adaptive control at the current crossroad [1].

2. Researching
Of the known adaptive control algorithms for a local crossroad, the most suitable is the statistical optimization algorithm. The algorithm allows using the information about the state of the crossroad at the moment, to determine the control parameters for the next moment in time, based on the probable forecasting of the current phase coefficients in conflicting directions [1, 2].

Phase coefficients are parameters that determine the degree of loading of the direction of motion in question, on the basis of which the cycle time is distributed between phases. They, in turn, are determined by the ratio of intensity to the saturation flux [3]. Since the value of the saturation flow is to a greater extent a stationary quantity, the main influence on the magnitude of the phase coefficients is exerted by the traffic intensity, therefore, it is possible to determine the dynamics of loading directions over time [4, 5].
Traffic intensity means the number of vehicles that have overcome an imaginary section of the road per unit of time [1]. This value is fundamental characteristic of the TF, which determines the amount of population’s demand for movement and affects other characteristics - speed and density, with medium and high traffic loads and directions, as well as road safety in general. That is why, traffic intensity is one of the main parameters studied during the development of projects and integrated traffic management schemes (ITMS), design of traffic lights, calculation of traffic control parameters and is a characteristic on the basis of which adaptive traffic control parameters. And also the moments of change of parameters at intersections can be established.

Along with this, a number of properties stand out that have a stable reflection in the urban TF [6, 7, 8]. The study of several of them - unevenness, dynamism, stationary, inertia of TF is possible based on knowledge about changing traffic intensity using mathematical methods.

The property of the dynamism of the TF is the change in traffic intensity over time (during the day, week, year) from minimum to maximum value. Changes in traffic intensity are permanent, repeating the dynamics from day to day, this shows the property of stationary TF [9, 10].

These changes do not occur simultaneously, but always during a certain period, so the inertia of the TF is manifested. Despite all these properties, changes in intensity are not completely constant, affects their random nature, which is manifested in the uneven of TF by the hour of the day, days weeks and months [11].

Experimental studies to study the daily intensity dynamics were conducted at one of the local crossroads of the city of Omsk Street. B. Khmelnitsky - Street. 3-rd Transport, where TF on approaches to crossroads are formed in "natural conditions" (there is no influence of neighboring regulated crossroads).

The intensity values were recorded by cameras (sensors) installed at a distance of 180 meters from the stop line of all approaches of the crossroads.

Figure 1 shows an example of averaging weekly data on traffic intensity in one of the sections of the RSN established on the basis of indicators of variation in intensity. Confidence intervals of intensity change during the week were established (with a probability of 95%), according to 5-minute values.

The size of the confidence interval can be judged on unevenness and stationary TF [9, 11]. In areas with a narrow confidence interval, there is a recurrence of the dynamics of the change in traffic throughout the working week. For this graph, the most accurately repeated periods of the day are night time, the period of morning increase in intensity and rush hour, the period of evening decline of intensity. This indicates the stationary of TF during the specified periods in the study area.

Figure 1. Average dynamics of changes in traffic intensity during the day, taking into account its weekly variation
A study based on 5-minute statistical data allowed us to establish that the deviations of the intensity from the average hourly values have a normal distribution with a high degree of reliability ($p = 0.925$) with a mathematical expectation of $\mu = 0.09$ and standard deviation $\sigma = 92.1$ units / h. In this case, the deviation from the average value will be within $\pm 150$ units / h with a probability of 95%, which is quite a significant value. The distribution histogram is shown in Figure 2.

![Figure 2. Distribution of intensity deviations from average hourly value](image)

In addition, to assess the unevenness of TF, the method proposed by Pechersky M.V. [12], built on the basis of the Fourier transform, was obtained an amplitude-frequency characteristic (AFC) of fluctuations in the intensity of TF (Figure 3). The resulting field of points AFC, indicates that fluctuations with a frequency of one per hour and above are random.

![Figure 3. Amplitude-frequency characteristic of fluctuations in traffic intensity during the day.](image)

Since the study of the properties of TF serves as the basis for the introduction of an adaptive traffic control system on an urban RSN, it can be carried out through the prism of control impacts [13]. For this, based on the intensity data taken at a 3-phase controlled crossroads, the dynamics of the change of phase coefficients (the ratio of intensity to saturation flux) for 3-adjustable directions was obtained [14, 15]. Combining the received values in the 3-dimensional graphic space allowed you to get a field of points (Figure 4).
Figure 4. Field of phase coefficients for 3-phase crossroads in 3-dimensional space.

The graph presented in Figure 4 indicates that the increase and decrease in the load of three independent from each other regulated directions occurs almost synchronously during the day. This suggests that the dynamism, inertia and stationary of these areas are identical.

Also, based on the phase coefficients, a cluster experiment was conducted aimed at assessing the need to change signal programs at the intersection in accordance with the increase in load in the studied regulated direction [16, 17]. The phase coefficient artificially increased from the initial value to that at which further use of the current signal program will cause delays greater than the transition to a more suitable signal program, even taking into account the presence of additional delays from the transition. A graphic reflection of the experiment is present in figure 5.

This experiment showed the ambiguity of decision-making on the appointment of a suitable signal program, because, as can be seen from Figure 5, there are areas of intersection of clusters. This indicates the presence of phase states for which several signal programs will be suitable that do not lead to significant differences in the obtained value of the objective function (delay) [18].

Figure 5. Boundary values of phase coefficients indicating the need to change the signal program for one of the regulated directions of the 3-phase crossroads: $p_i$ - initial phase coefficient; $p_p$ - phase transition coefficient
From the presented material, we can conclude that the management at local regulated crossroads in cities can assume a certain number of options (more than 1) that can be consider optimal and the results of their possible application will not differ significantly in the obtained value of the objective function [19]. The development and application of adaptive control at such crossroads based on the accounting and analysis of the properties of TF will reduce transport delays by about 35%

3. Conclusion
The study of changes in traffic intensity on urban highways allows you to establish the dependencies characteristic of several properties at once: unevenness, dynamism, inertia and stationary. When studying the issue of transport management in urban conditions, the most interesting are changes in intensity in the daily cycle and its seasonal fluctuations.

Currently, to study the properties of TF, there are a fairly large number of modern devices for accounting for intensity and other parameters of movement, and there is also a wide range of methods for studying them, some of which are given in this article. A fundamental study of the properties of TF and the dependencies characterizing them makes it possible to use and apply the acquired knowledge in the development and implementation of innovative algorithms and systems for local adaptive traffic control at the crossroads of the RSN.

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