Adaptive Algorithm of Intersection Management Based on Road Marking Adjustment Optimization

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***Abstract*—**The methods of transport flows managing has a number of shortcomings. An adaptive method based on the systematic configuration of the use of variable marking schemes of a road that leads to the junction, with the help of controlled signs is offered, which significantly increases its capacity and reduces the transport delay at the traffic lights. The paper proposes a formula presentation of markup and classifies the markings.

***Keywords*—** adaptive control, road marking, formula presentation of markup, traffic light object, competing traffic flow.

I. Introduction

Modern road traffic is a complex dynamic system of people, vehicles and road infrastructure elements interference. To provide fast and safe traffic in such conditions requires the use of a complex of organizational and architectural planning activities for highways building, as well as the use of modern technical means of traffic organization based on information technology.

At the same time, the current experience in the use of technical means considers individual vehicles and does not take into consideration the interrelationships between the heterogeneous components of the road traffic [1, 2], which makes it urgent to develop new means of traffic automation (especially within the intersections) that allow its complex regulation based on constantly changing road conditions. The discrepancy between the existing street and road network of large cities in conditions of loaded and overloaded traffic flows makes the movement on regulated nodes more complicated. This situation requires reconsidering of the theory and practice of street traffic management and the use of modern tools and management methods.

Investigating traffic congestion as well as designing new transport management systems, special attention should be paid to such a road regulation element as the intersection. The intersection is the place of crossing of several roads. The most common crossing is X-shaped and it is the intersection of two roads. Here there is a decrease in the capacity of the way, since a part of time for the movement must be transferred to the intersecting (competing) stream. A traffic light at an intersection performs the function of a switching device that provides the alternate right for motion through a crossroads to motor vehicles (MV) from competing destinations.

Because of the stochastic change in MVs intensity approaching the intersection from different directions makes the task of satisfactory, adequate management of the crossroads difficult to achieve. All researches in the field of traffic management in the street network (SN) focuses on improving management at the SN nodes, through traffic control [3], i.e.: there is a resolution of the situation that has already taken place at the intersection. Frequently, the situation is very unfavorable with a large number of MVs stopped at the traffic lights. Control actions in this case are the changes in the traffic light cycle duration, time, the number of traffic lights and their order of succession [4, 5]. Often this set of changes in the parameters of a traffic light

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object (TLO) is not enough, and the "traffic jam" at the crossroads grows.

The failure of the functioning of the transport system occurs as a result of congestion on the transport network. The appearance of congestion, when there is a reserve of network capacity, is explained not only by the low optimality of traffic signaling, but also by its insufficiency. An additive change in road marking should be an addition to the traffic regulation at the crossroads by means of TLO.

The intensity of traffic in a city during the day, week and year varies significantly. Road accidents (traffic accidents), road closures, roadway repairs and other temporary factors also affect the change in the traffic intensity. Therefore, a significant change in the intensity of motion ratio along the directions is possible. In order to take into account the unevenness of the traffic, a flexible system is needed that allows changing the direction of motion along the lanes, for example, increasing the intensity of traffic to the left requires an increase in the number of lanes in a given direction. The system in this case changes the direction of motion along one of the bands with the help of controlled signs and the motion to the left switches to the mode of two-lane or one lane is used for motion right and left.

The ability to use variable schemas with managed signs and operational control increases the capacity of the SN significantly and reduces the transport delay, therefore requires extensive use in urban transport systems.

II. Problem Formulation

The existing road marking has a number of shortcomings, which can be divided into two groups:

- Disadvantages for drivers.
- Disadvantages for the traffic police and municipal services.

One of the main problems faced by drivers in the process of driving on roads with standard marking is its permanence (immutability).

When driving along the stage to the next crossroads, the driver does not know the marking at this intersection until arriving. In this case, if the driver was not aware of prohibition to turn in a certain direction within a specific intersection, he may have to travel an additional distance to the next intersection, which involves additional time and material costs.

In the second group of deficiencies, one can mention an increased risk of road accidents. Thus, when moving along a stream (in a bundle) and approaching a crossroads in order to continue their movement at minimum costs and keep to the chosen route, drivers begin to rearrange themselves actively. Either if the subsequent marking is very different from the previous one or the car changes direction, or also in case of inattentive attitude of drivers to warning signs and sharp rearrangement, traffic accidents (road accidents) occur frequently.

In addition, the issues connected with the strength of standard markup in the process of exploitation appear. Thus, point 5.1.10 of General Specification 1231-2000 "Road markings: general characteristics" says that road markings made of thermoplastics, cold plastics or other similar materials should have functional strength of at least 1 year, and for paints and enamels the time-span should be not less than 6 months. [6].

However, a longer period is not established as well as the maximum lifetime, which causes the appearing of the places where marking is almost invisible or completely absent within the boundaries of cities. This lack, in addition, affects drivers who, without knowing anything, can violate the rules of the road.

Thus, the presence of a number of shortcomings that keeps from the effective implementation of traffic on urban roads requires the introduction of new means of regulation and control. It is proposed to install electronic scoreboards on the lanes between intersections that will choose the marking for vehicles moving in the stream and, if necessary, regulate the movement of cars on the required tracks with minimal changes. At the same time, drivers are notified in advance about the form of marking at the upcoming crossroads, as the electronic scoreboard is installed at a distance of ¾ from the upcoming intersection, and the drivers have enough time for the necessary rearrangement.

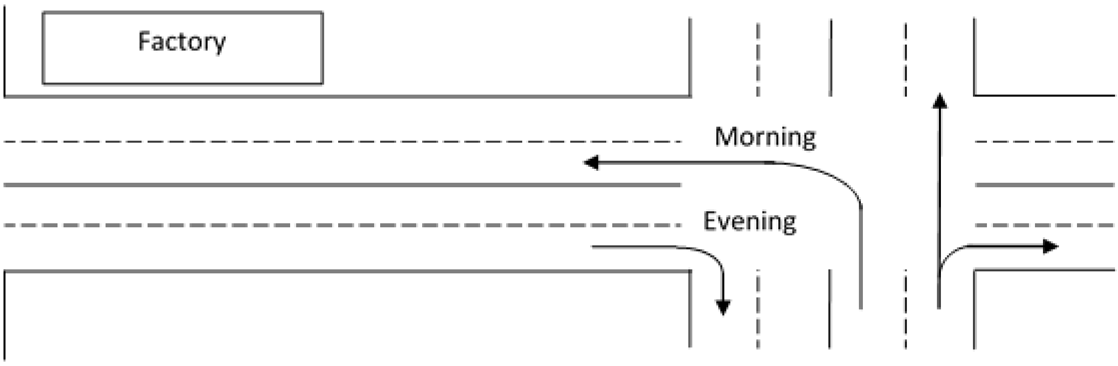


Fig.1 - SN fragment

Figures 1 and 2 show an example the road marking change during the day, regarding the structure of traffic flow in the morning and evening hours. At Figure 1 NS fragment with a clear center of gravity (factory) is shown. In the morning hours, MVs leave the main road at the crossroads to the left for the factory. In the morning, the markings shown are on Figure 2(a) or (b). In addition, marking 2(b) can pass more left cars. Although the marking 2(c) is typical for the evening. The indicator of marking change is the information from transport detectors located along each strip. For example, the appearance of a queue on the left lane before crossing, fixed by transport detectors, will be a signal for the control system to change the marking and increase the number of lanes for this category of transport.

(a) (b) (c)

Fig.2 - Markup options for the represented NS fragment

III. Formula Presentation of Marking

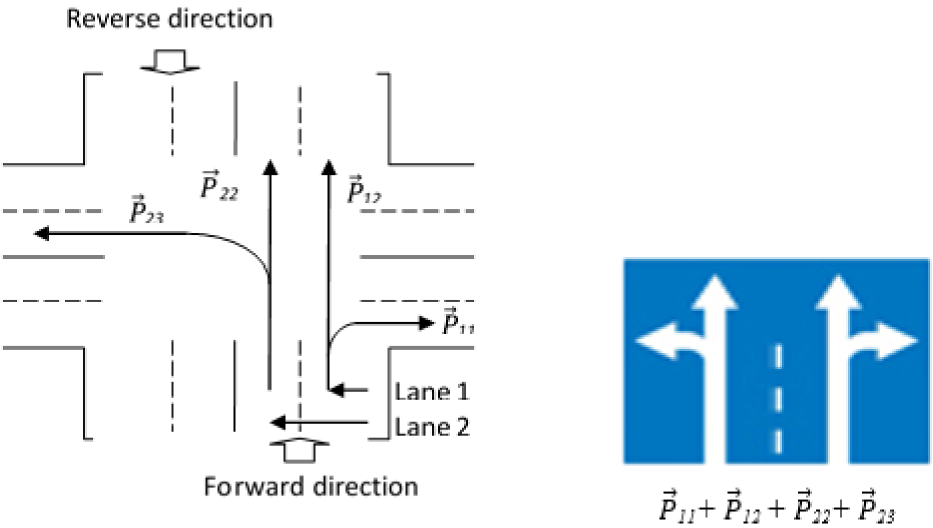
In order to manage the electronic scoreboard of the variable marking efficiently and hence the intersection, it is necessary to have a database of all possible markings. It is done for all the lanes of one direction of the road (the road is divided by a solid line into the forward and reverse direction). Each direction is divided by a dashed line into traffic lanes with the numbering $i = \overline{1, m}$ starting from the right edge of the curb of each direction of the road. The marking of the i-th lane is the vector $\vec{P}_{ij}$, pointing to one of the three directions $j = \overline{1,3}$ of the traffic from the i-th intersection lane: to the right 1, straight 2 and to the left 3.

Therefore, the vector $\vec{P}_{11}$ indicates the movement from the first lane to the right, and the vector $\vec{P}_{12}$ for the movement along the first lane straight, the vector $\vec{P}_{23}$ indicates the turn from the second lane to the left. Thus, the marking vector $\vec{P}_{ij}$ reflects the possibility of moving in one direction or another with each of the lanes. Marking for one direction of the road is a collection of $\vec{P}$ vectors $\vec{P}_{ij}$:

$$\vec{P} = \vec{P}_{11} + \ldots + \vec{P}_{ij} + \ldots + \vec{P}_{m3} \quad (1)$$

Where m is the number of lanes of one direction of the road, $= \overline{1,m}$, $j = \overline{1,3}$. Here the sign "+" means not the arithmetic summation, but the union of the elements.

Figure 3(a) shows the intersection with the road markings for the forward direction of traffic. Figure 3(b) shows the road sign of this marking with its formula presentation. We arrange the brackets in the formula notation for this sign as follows: $\vec{P}=(\vec{P}_{11}+\vec{P}_{12})+(\vec{P}_{22}+\vec{P}_{23})$. Then the set of vectors in each bracket refers to one lane of motion. This will be a formula presentation of a separate lane, that is, in each bracket, therefore, a set of vectors, or otherwise, directions of movement from a particular lane. Formulas of marking with banding along the lane are located in the second column of the Table I



(a) (b)

Fig.3 - Example of a two-way intersection and its corresponding sign with its formula presentation

It is possible to have a variant of grouping by the direction. If the first index (the number of the lanes) was decisive for grouping along the lane, then the second index of the vector (the direction of motion) is the determining factor for grouping along the direction. Arrange the brackets in the previous example as follows: $\vec{P}=\vec{P}_{11}+(\vec{P}_{12}+\vec{P}_{22})+\vec{P}_{23}$. Record the markings when grouping in the direction we put in the third column of Table I.

Here the transformations in the form of summation of vectors are already possible. Vectors $\vec{P}_{12}$, $\vec{P}_{22}$ have one direction 2 (forward). We replace the expression in parenthesis with the general direction vector forward $\vec{P}_2$. In addition, we replace the vectors $\vec{P}_{11}$, $\vec{P}_{23}$ by $\vec{P}_1$ and $\vec{P}_3$. Then we obtain $\vec{P}=\vec{P}_1+\vec{P}_2+\vec{P}_3$. We denote by p the capacity of one lane (the number of cars passing through the cross section of the band per unit time, cars/min.). Then the modules of the vectors $|\vec{P}_1|$, $|\vec{P}_2|$ and $|\vec{P}_3|$ distributed as follows $0.5p$, p and $0.5p$ (see Figure 3). Coefficient 0.5 indicates that direction 1 (to the right), and direction 3 (to the left), in the given marking allocated 0.5(half) of lane. At the same time, a whole lane is allocated to direction 2 (forward).

We compose an ordered triple from the bandwidth of each direction ($|\vec{P}_1|$, $|\vec{P}_2|$, $|\vec{P}_3|$) or $(0,5, p, 0,5p)$. We normalize the triple by dividing each of its elements by $|\vec{P}|=2p$ (the carrying capacity of the whole direction of motion along all its two lanes). Then we obtain $(|\vec{P}_1|/|\vec{P}|, |\vec{P}_2|/|\vec{P}|, |\vec{P}_3|/|\vec{P}|)$, or $(0,5p/2p, p/2p, 0,5p/2p)$, or $(0,25, 0,5, 0,25)$. The ordered triple ($0.25, 0.5, 0.25$) is a numerical characteristic of a particular, given markup. Each coordinate of the triple (w_1, w_2, w_3) indicates the share w_j, $j = \overline{1,3}$, which is the specific direction (right, forward, left) in the total capacity of the entire direction of travel. All the triplets are added to the fourth column of Table I.

It should be noted that the recording in the direction is more informative, since it allows us to estimate the resource allocated by this marking for one or another direction of movement. The obtained numerical characteristics can be used for adaptive control by selecting the closest marking for an MV (bundled of MVs) approaching to the crossroads. The structure of the bundle (under the structure one understood the ratio of the number of cars traveling at the intersection to the right, forward and left) must coincide or be closest to the layout structure.

A pack $\vec{X}$ of n vehicles $\vec{X}=\vec{X}_1+\vec{X}_2+\vec{X}_3$ is approaching to the intersection, where $|\vec{X}_1|=n_1$ is the number of cars that will go to the right, $|\vec{X}_2|=n_2$ is the number of cars going forward direction and $|\vec{X}_3|=n_3$ - to the left. Let us make the objective function of the situation from the marking parameter $\vec{P}$:

$$min\ F(\vec{P})=||\vec{X}|-|\vec{P}||=||\vec{X}_1|-|\vec{P}_1||+||\vec{X}_2|-|\vec{P}_2||+||\vec{X}_3|-|\vec{P}_3|| \quad (2)$$

Let us move from the parameter $\vec{P}$ to the next objective function:

$$min\ Z(\vec{P})=|n_1/n-|\vec{P}_1|/|\vec{P}||+|n_2/n-|\vec{P}_2|/|\vec{P}||+|n_3/n-|\vec{P}_3|/|\vec{P}| \quad (3)$$

The minimum of the objective function $Z(\vec{P})$ is a minimum for the function $F(\vec{P})$, i.e. both functions reach a minimum for one parameter $\vec{P}$. We are transforming the expression (3):

$$min\ Z(\vec{P})=|n_1/n-w_1|+|n_2/n-w_2|+|n_3/n-w_3| \quad (4)$$

Expression (4) is a universal tool for adaptive selection of appropriate marking for the traffic flow entering the intersection. That is, from all the markings $\vec{P}$ of Table I we take the marking $\vec{P}^*$ at which the minimum of the function $Z^*(\vec{P}^*)$ is reached. It provides the fastest MV traffic at the crossroads.

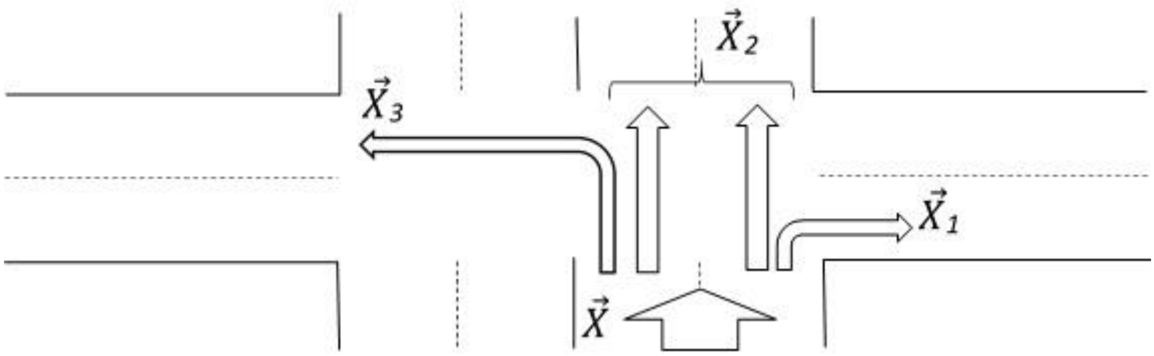


Fig.4 - Example of a vector traveling bundle representation

IV. CLASSIFICATION OF MARKINGS

We will compose all possible markings for a two-lane entrance to the intersection. The number of all such markings is 17. All the markings obtained can be classified into three groups (Table I):

- Actual.
- Force majeure.
- Irrelevant.

TABLE I
FORMULAS OF TWO-LANE MARKINGS

#	Formula of markup with grouping along the lane	Formula of markup with grouping along the movement direction	Marking numeric characteristics (w_1, w_2, w_3)	Traffic sign
Actual				
1	$(\vec{P}_{11}+\vec{P}_{12}) + (\vec{P}_{22}+\vec{P}_{23})$	$\vec{P}_{11}+(\vec{P}_{12}+\vec{P}_{22})+\vec{P}_{23}$	(0.25 , 0.5 , 0.25)	
2	$(\vec{P}_{11}+\vec{P}_{12}+\vec{P}_{13}) + \vec{P}_{23}$	$\vec{P}_{11}+\vec{P}_{12}+(\vec{P}_{13}+\vec{P}_{23})$	(0.16 , 0.16 , 0.66)	
3	$\vec{P}_{11}+(\vec{P}_{21}+\vec{P}_{22}+\vec{P}_{23})$	$(\vec{P}_{11}+\vec{P}_{21})+\vec{P}_{22}+\vec{P}_{23}$	(0.66 , 0.16 , 0.16)	
4	$(\vec{P}_{11}+\vec{P}_{12})+\vec{P}_{23}$	$\vec{P}_{11}+\vec{P}_{12}+\vec{P}_{23}$	(0.25 , 0.25 , 0.5)	
5	$\vec{P}_{11}+(\vec{P}_{22}+\vec{P}_{23})$	$\vec{P}_{11}+\vec{P}_{22}+\vec{P}_{23}$	(0.5 , 0.25 , 0.25)	
Force majeure				
6	$(\vec{P}_{11}+\vec{P}_{12})+\vec{P}_{22}$	$\vec{P}_{11}+(\vec{P}_{12}+\vec{P}_{22})$	(0.25 , 0.75 , 0)	
7	$\vec{P}_{12}+(\vec{P}_{22}+\vec{P}_{23})$	$(\vec{P}_{12}+\vec{P}_{22})+\vec{P}_{23}$	(0 , 0.75 , 0.25)	
8	$(\vec{P}_{12}+\vec{P}_{13})+\vec{P}_{23}$	$\vec{P}_{12}+(\vec{P}_{13}+\vec{P}_{23})$	(0 , 0.25 , 0.75)	
9	$\vec{P}_{11}+(\vec{P}_{21}+\vec{P}_{22})$	$(\vec{P}_{11}+\vec{P}_{21})+\vec{P}_{22}$	(0.75 , 0.25 , 0)	
10	$\vec{P}_{11}+(\vec{P}_{21}+\vec{P}_{23})$	$(\vec{P}_{11}+\vec{P}_{21})+\vec{P}_{23}$	(0.75 , 0 , 0.25)	
11	$(\vec{P}_{11}+\vec{P}_{13})+\vec{P}_{23}$	$\vec{P}_{11}+(\vec{P}_{13}+\vec{P}_{23})$	(0.25 , 0 , 0.75)	
12	$\vec{P}_{11}+\vec{P}_{23}$	$\vec{P}_{11}+\vec{P}_{23}$	(0.5 , 0 , 0.5)	
13	$\vec{P}_{11}+\vec{P}_{22}$	$\vec{P}_{11}+\vec{P}_{22}$	(0.5 , 0.5 , 0)	
14	$\vec{P}_{12}+\vec{P}_{23}$	$\vec{P}_{12}+\vec{P}_{23}$	(0 , 0.5 , 0.5)	
Irrelevant				
15	$\vec{P}_{13}+\vec{P}_{23}$	$(\vec{P}_{13}+\vec{P}_{23})$	(0 , 0 , 1)	
16	$\vec{P}_{11}+\vec{P}_{21}$	$(\vec{P}_{11}+\vec{P}_{21})$	(1 , 0 , 0)	
17	$\vec{P}_{12}+\vec{P}_{22}$	$(\vec{P}_{12}+\vec{P}_{22})$	(0 , 1 , 0)	

Those markings are actual that use all three outputs from the intersection. These are working markings that are constantly used in the process of controlling the intersection. The frequency of their use is different and depends on the structure of traffic flows crossing the intersection (here the transport stream is considered as the ratio of vehicles turning right, right and left), i.e. the closest marking is set on the electronic scoreboard for the traffic intersecting the intersection. "The closest" means that out of the entire set of markings, only this intersection will leave all cars in the minimum time.

Force majeure markings use only two outputs from the intersection of the three possible. With this marking, one exit from the intersection is closed. This group of markings is not used so often. Only in the case of an accident or during maintenance work to close the passage through the street, which refers to this exit from the intersection.

Out-of-date markup has only one exit from the intersection. This group of markings is practically not used. In Table I, layouts are arranged in decreasing order of use.

Starting from the moving MVs with the characteristics $\vec{X}(n_1, n_2, n_3)$ moving to the intersection at a particular (current) time moment, there is a vector (marking) $\vec{P}$ by searching through Table I to minimize the function $Z(\vec{P})$ based on the expression (4). The search is done by the numerical characteristics of the vector $\vec{P}(w_1, w_2, w_3)$. Thus, an adaptive selection of the closest to the markup flow is carried out, which is constantly replaced by an electronic scoreboard.

V. CONCLUSION

Based on the above analysis of the possibility of using electronic displays with adaptive algorithm for the integrated intersection management of road traffic in cities, it can be noted, that currently this tool is the most modern and effective. The effectiveness of the proposed system is determined by the possibility of increasing the discipline of drivers and safety on the roads, as well as by economic considerations, manifested in reducing fuel consumption and increasing the resource of cars for drivers and reducing the costs of maintaining standard marking in an acceptable state for public services and the country itself.

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