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INTELLIGENT SYSTEM OF TRAFFIC LIGHT CONTROL WITH DYNAMIC CHANGE PHASES OF TRAFFIC FLOWS ON CONTROLLED INTERSECTIONS

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ABSTRACT

There was method of making an effective system of traffic-light control of the traffic through the intersections in one direction according to which the phase coefficients for each cycle of traffic-light control are computed in real-time using the data of traffic intensity detected by transport detectors. Thus, the built-in traffic control system will be dynamically adapted to the change in the intensity of traffic flows, and the structure of the cycle and its duration will be changed taking into account the parameters of the traffic flow at the intersection. Accordingly, the traffic light cycle, where each cycle has the minimum required duration, will be most effective and will ensure uninterrupted traffic, the lack of traffic jams and the convenience for the pedestrian crossings.

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Introduction. The growing role of the transport in the society life requires provision of the necessary conditions for ensuring the efficiency and quality of the operation of traffic control systems for urban and long-distance passenger and cargo transportation [1]. At the same time, road transport is the most dangerous in comparison with other means of transport. At present, the death toll in the incidents is about 1.25 million people in the world, great more people are injured. So according to the traffic safety department of the Ministry of Internal Affairs, from 2014 to 2016 in Ukraine, 82,400 accidents were registered with people involved, including 13,32 thousand people killed and 101,5 thousand injured. At the same time, one of the main accident causes is uncontrolled pedestrian crossings - 38% and violating the rules of intersection crossings - 30%. According to the World Bank (data of 2014), the loss of the Ukrainian economy from road traffic accidents is about $ 4.5 billion annually [2].

Therefore, the development of new models and methods for improving the traffic-light of the traffic flow control system becomes particularly relevant for optimizing the functioning of urban transport networks. To do this, it is necessary to constantly equip the street-road network with modern software and technical means of the traffic control [3]. And accordingly, the development and implementation of intelligent transportation systems is an effective means of improving road safety.

Analysis of recent research and publications.

Today, traffic-light of the traffic flow control systems are carried out on the basis of the constant phases of the traffic flow in different directions, computed on the basis of technical parameters, output data and statistics [4, 5]. The basic parameters, which the traffic-light control system operation is based determine the operating time (signaling) of the traffic light green signal for each direction, the level of loading, the intensity of the flow and the throughput of the intersection. The throughput of the main line at the intersection of the stop line is determined by the bandwidth of one lane, by the lanes number, by traffic organization and the control modes [6].

Progress in the field of computing and mobile communications has created favorable conditions for the development and implementation of intelligent control systems in various fields of business, especially transport [7]. Intelligent transportation systems (ITS) are based on application of modern software and hardware means of registration and real-time processing of data flows on the involved elements operation of the transport infrastructure, including the movement of people and goods.

Currently, one of the priority directions of application of intelligent transportation systems is to ensure road safety. Thus, in order to realize the requirements of the traffic safety for the society, intelligent transportation systems for Ukraine should become an integral part of the transport complex [8].

The importance of further development of the theory and practice of intelligent transportation systems application necessitates the existence of numerous scientific researches on this subject. The intelligent transportation system application in the city network is a significant step forwards the transport system development to European and world levels, as shown in [9], where the simulations and research of traffic flow control problems in the urban transport network was conducted. Fundamental foundations for the development and implementation of ITS are given in [10 – 12]. In scientific papers [13 – 15] an analysis of perspective directions of intelligent transportation systems application was carried out.

One of the most dangerous places in urban transport systems is the presence of a heterogeneous network of street and road intersections in one direction. This is due to the fact that at such intersections, the interaction of traffic flow with road conditions depends on the influence of a large number of factors. Therefore, in order to manage the traffic and pedestrians in such cases, the system of traffic control is used.

The purpose of the paper is to develop a method for traffic-light control at intersections, which provides a reduction in idle time at the intersection in anticipation of the green light due to the dynamic correction of the passage phases duration for vehicles and pedestrians, depending on their number, recorded by the corresponding detectors on theier way. The data use on the number of vehicles arriving at the intersection will allow real-time changes in the length of phases of the traffic light control and to make an adaptive system for controlling the traffic through the intersection in one direction. The peculiarity of the presented researches is that this paper highlight the problems of making the intelligent traffic-light control system with the dynamic change of the traffic flows on controlled intersections.

The research results.

Consider the computation of the intersections throughput capacity with traffic lights when crossing the stop line, Fig. 2.

There are two lanes at the crossing of the stop-line of the intersection. Direct flows occupy both lanes, right turns are made from the extreme right lane, the left - on the other, while making obstacles for the subsequent direct flow. The traffic in this section in all directions is carried out in one phase. The intersection throughput at crossing the stop line (P_p) is determined by the formula:

$$P_p = \eta \cdot P_t , \tag{1}$$

wherein P_t – bandwidth of one lane [15]; η is the coefficient that considers the throughput reduction due to obstacles from the left-turning motion, depending on the left turning traffic proportion in the flow – q: $\eta=f(q)$. The recommended η coefficient values for intersections of one-lane and multi-lane roads [16] are given in Table 1.

Table 1. Recommended values of the left-turning movement coefficient

The share of vehicles *q*, (%)		0	10	20	30	40
Value $\eta=f(q)$ for intersection	one-lane roads	1,0	0,65	0,6	0,55	0,5
	multi-lane roads	2,0	1,65	1,6	1,55	1,5

Saturation transport flow is the main parameter of the intersection operation that determines the maximum traffic intensity per hour through the stop line when the traffic signal is enabled. The saturation flow value depends on a number of factors, but above all, on the intersection geometric parameters:

$$M = f(B), \qquad (2)$$

wherein *B* - the width of the road section.

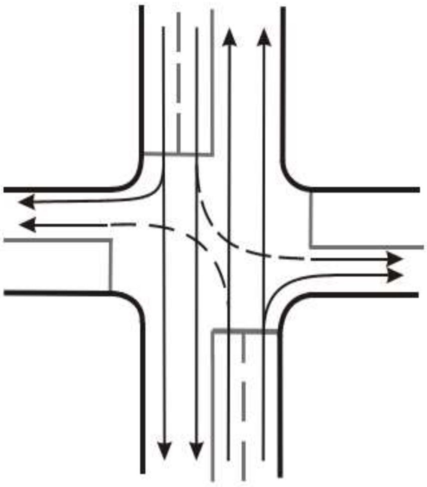

Fig. 1. Scheme for distributing flows of different directions along the lanes

Taking into account the uneven traffic distribution along the roadway width, the saturation flow amount is calculated as follows [5]:

$$M = 525 \cdot B / (p + 1,75 \cdot q + 1,25 \cdot s), \qquad (3)$$

wherein *B* - width of the roadway, m; *p*, *q*, *s* - share of traffic flow distribution in the "straight", "left" and "right" directions respectively.

The influence of other factors is taken into account by the corresponding coefficients.

The minimum duration of the control cycle is computed by the Webster mathematical simulation, which allows considering the influence of factors characterizing the composition and nature of the motion, provided that the number of vehicles arriving at the intersection is equal to the number of vehicles that can leave it. In accordance with the Webster simulation, the minimum cycle length is defined as follows:

$$T_{\min} = L / (1 - Y), \qquad (4)$$

wherein *L* is the time spent in a cycle, sec; *Y* is the total phase intersection factor.

In order to determine the optimal cycle duration, it is necessary to consider the condition where the average delay at the intersection is minimal. Delay is computed by the formula [6]:

$$d = \frac{C(1-\lambda^2)}{2(1-\lambda x)} + \frac{x^2}{2q(1-x)} + 0,65 \cdot \left(\frac{C}{q^2}\right)^{1/3} \cdot x^{(2+5\lambda)}, \qquad (5)$$

wherein d is an average delay of one vehicle at the intersection;
C is the duration of the cycle;
q is the intensity of movement in the direction being considered;
λ is the an effective phase proportion in the control cycle;
x is the phase saturation degree.

With a decrease in cycle duration, the delay increases due to the nonproductive particle in the control cycle. But with an increase in the cycle duration, the delay also increases, because the vehicles at the intersection do not have time to pass it. The minimum delay is achieved when the ratio of effective phase proportions is equal to the ratio of the corresponding phase coefficients. The most optimal duration of the traffic light control cycle is 25–120 s. The pedestrian phase duration is determined from the condition of the time sufficiency for the pedestrian to cross the travel section during this tact. As the main value of the pedestrian phase duration, the greatest calculated value is taken [5].

The average traffic characteristics at the intersection are determined by the results of field observations. To do this, measurements of the following characteristics are carried out:

– intensity of traffic flow in different directions at the intersection;
– composition of transport flows;
– intensity of pedestrian flows;
– saturation flows in different directions;
– vehicles average speed in the intersection zone.

Determination of saturation flows is performed for each direction of different control phases. On the controlled intersections, they are determined by the dependence:

$$M_{Hij} = \frac{3600}{n}\sum_{z=1}^{n}\frac{m_z}{t_z}, \tag{6}$$

wherein i is the control phase number; j is traffic direction number; n is measurements number;
m_z is the number of vehicles that passed through the stop-line during time t_z.

To determine all characteristics, timing t begin with the moment of turning the green light on of the traffic light and end at the moment of crossing the "stop-line" by the last vehicle in the line. Measurements are repeated 10 times, and with over 10 vehicles in line 3 – 5 measurements is enough [5].

The starting data for computing the operation mode of traffic signaling is the characteristics of traffic at the intersection. The parameters computation of the traffic-light control system is carried out by such an algorithm [5].

1. For the direction of movement in each control phase determine the phase coefficients:

$$Y_{ij} = \frac{N_{ij}}{M_{Hij}}. \tag{7}$$

Wherein Y_{ij} is the phase coefficient of the j-th direction of motion in the i-th control phase;
N_{ij} is the intensity of movement in the j-th direction of the i-th control phase, vehicles/h.
M_{Hij} is the saturation flow in the j-th direction of motion in the i-th control phase, vehicles /hour.

As the computational phase coefficients for each phase, the highest values of Y_{ij} in each phase are taken. If the traffic flow is passed through two phases, then the phase coefficient is computed separately for it. If this phase coefficient is greater than the sum of the computed phase coefficients of the phases during which it is skipped, then the computed phase coefficients increase.

2. The duration of intermediate cycles in each phase is computed by the formula:

$$t_n = \frac{V_a}{7{,}2 \cdot a_t} + \frac{3{,}6(l_j + l_a)}{V_a}, \tag{8}$$

wherein V_a is the vehicles average speed in the intersection zone, km/h;

a_t is average deceleration of the vehicle when the traffic signal is turned on, m/s ^{2};

l_j is the distance from the stop-line to the longest-conflict point of intersection with vehicles that begin to move in the next phase;

l_a – the length of the vehicle most commonly spotted in the flow, m.

Values V_a are determined based on the average empirical traffic flow data through the intersection. Deceleration a_t = 3 – 4, m/s^2.

Proceeding from the requirements of traffic safety, the value of the duration of intermediate facts is computed by the formula (11), but must be not less than 4s.

Since the intervals among sequentially arriving vehicles to the intersection are usually different, the length of the cycle of traffic control is computed from the Webster formula:

$$T_{cl} = \frac{1,5 \cdot T_n + 5}{1 - Y}, \quad (9)$$

wherein T_n is the sum of the intermediate cycles t_n, s;

Y is the sum of the computed phase coefficients.

$$T_n = \sum_{i=1}^{k} t_{ni}, \quad (10)$$

$$Y = \sum_{i=1}^{k} Y_i, \quad (11)$$

wherein k is the control phases number.

Based on the requirements of traffic safety, regardless of the computed value, take T_{cl} = 25 – 120 s.

3. The duration of the basic tact in the i-th control phase is computed by the formula:

$$t_{ti} = \frac{(T_{cl} - T_n) \cdot Y_i}{Y}, \quad (12)$$

T_{ti} take at least 7 s to ensure traffic safety requirements.

4. The time required to for pedestrians passing in any direction is computed by the formula

$$t_{pp} = 5 + \frac{B_{rw}}{V_{ps}}, \quad (13)$$

wherein B_{rw} is the width of the travel section, m;

V_{ps} is the pedestrian speed, m/s.

Since the intensity of traffic flows varies depending on the time of day, day of the week, and season, therefore, in order to ensure the effectiveness of the traffic-light control, it is proposed to compute the phase coefficients for each cycle of traffic-light control in real-time according to the formula (7) using the data of the traffic intensity in the i-th phase in the j-th direction of the traffic detected. The traffic detectors allow to determine the vehicles type, number and speed, when passing through intersection, determining the parameters of traffic flows. Thus, the system of traffic-light control on such an algorithm will be dynamically adapted to the change in the intensity of traffic flows, and the structure of the cycle and its duration will be computed taking into account:

– the current intensity of traffic and pedestrians at the intersection;

– crossing capacity;

– other traffic and road characteristics of intersections.

In this case, the traffic light cycle, where each cycle will have the minimum required duration, will be most effective. It is such a structure of the traffic light cycle that can provide uninterrupted traffic, the absence of traffic jams, and the convenience of the pedestrian crossing.

The results of computation of the cycle of traffic lights in accordance with the proposed algorithm implemented in the Pascal programming language applying the traffic detectors data determine the following parameters:

– saturation flow for first phase of the first direction is 768.6 vehicles/hour;
– saturation flow for first phase of second direction is 691.1 vehicles/hour;
– saturation flow for second phase of first direction is 860.1 vehicles/hour;
– saturation flow for second phase of second direction is 740.7 vehicles/h;
– time of intermediate cycles is 7.39 s;
– time of the green light on for pedestrians is 15,77 s;
– time of the green light on for the first phase is 15,77s;
– time of the green light on for the second phase is 15,77s;
– cycle time is 38,92 s;
– intersection throughput capacity is 2689 cars per hour.

At the same time, the intersection throughput with fixed control time for the considered parameters is less and equals 2612 vehicles/h.

Conclusions from this research and prospects for further studies in this direction. The use of traffic control systems can significantly improve the conditions for the traffic and pedestrians through the intersections in one direction. At the same time, the operating modes application of traffic lights with stationary phases of traffic and pedestrians leads to an unreasonably overestimated capacity, and, consequently, additional time losses at traffic lights, reduction of traffic safety, increased fuel consumption and more intense environmental pollution by exhaust gases.

Existing methods for computing the full cycle of traffic-light control are based on statistical data on the traffic and pedestrians at these intersections with the fixation of their number, type, time, conditions and other parameters.

The most rational way to increase the efficiency and safety of traffic at the intersections is to improve the systems of traffic-light control by introduction of intelligent adaptive control systems. In accordance with the proposed approach, the intelligent traffic control system is based on the phases length of the vehicles passing through intersections computed in real time on the basis of the initial data obtained from the transport detectors on the available queues of cars and pedestrians. The application of such an approach will increase traffic safety and traffic efficiency and pedestrian crossings, as well as reduce traffic accidents and fuel consumption.

It should be noted that the practical implementation of intelligent traffic control systems is a complicated engineering and technical task and requires the concentration problem of mutual efforts of specialists in transport and information technologies.

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