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THE PROCESS OF TRAFFIC DELAYS FORMATION AT A REGULATED INTERSECTION DURING CONGESTION

ПРОЦЕСС ОБРАЗОВАНИЯ ЗАДЕРЖЕК ТРАНСПОРТА НА РЕГУЛИРУЕМОМ ПЕРЕКРЕСТКЕ ПРИ ПЕРЕГРУЗКЕ

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Abstract. *Delays (loss of time) of transport due to reduced speed or forced downtime on the street and road network can be attributed to economic losses. The article deals with the process of formation of internal delays of transport during congestion.*

Keywords: *signalized intersections, traffic delays, lane congestion, saturation factor, first stop-line, conditional second stop-line.*

Introduction

Currently, the Belarusian National Technical University (BNTU) has developed a methodology for assessing the quality of traffic on a given section of the street and road network. An integral part of this technique is the calculation of specific transport delays (per 1 vehicle) with the lane load factor value. Calculations are performed both for vehicles stopped at the first stop line and for vehicles stopped at the conditional second and conditional third stop lines.

The conditional second stop line is formed by a turning car that stopped in the first (right-turning) lane and hinders the movement of other cars in this lane (both transiting and right-turning). The conditional third stop line is located directly in front of the crosswalk. In case of a conflict left turn conditional second stop line is formed by a turning car (from the leftmost lane), which stopped to pass the main transit flow of the opposite direction. The conditional third stop line is located directly in front of the crosswalk.

Calculations according to this methodology are valid if the ratio of the intensity of arriving traffic to the capacity of a given lane (stop line, intersection) is less than unity. If this ratio is greater than unity, the length of the queue of cars in front of the intersection increases indefinitely. The lane load factor exceeds the value of 0,93 (normative permissible value). Congestion is such a short- or medium-term condition of a conflict object, when incessant queues of vehicles are formed on separate lanes or directions. In such a case $X > 0,93$. The BNTU methodology is accepted to calculate the specific traffic delay for the peak period by the Brilon and Wu's formula [1, 2]:

$$d = \frac{C \cdot (1-\lambda)^2}{2 \cdot (1-\lambda \cdot X)} + \frac{N_o}{q_н \cdot \lambda} \quad \text{(sec/veh)}, \tag{1}$$

where C – cycle length (sec);

λ – the fraction of the green signal in the cycle. Calculated by the formula

$$\lambda = \frac{t_z}{C}, \tag{2}$$

where t_z – effective green time (sec);

q – arrival rate (veh/sec);

X – degree of saturation (flow to capacity ratio). Calculated by the formula

$$X = \frac{q}{q_{н} \cdot \lambda}, \tag{3}$$

where $q_{н}$ – saturation flow (veh/sec).

According to Brilon and Wu [1, 2], in the presence of congestion with the degree of saturation $X_o < X < 1{,}14$ queue length (veh/sec) at the intersection at the end of the green light is calculated by the formula

$$N_o = 524 \cdot \frac{T_o}{3600} \cdot q_{н} \cdot \lambda \cdot \left[1{,}09 \cdot X - 1 + \sqrt{(1 - 1{,}09 \cdot X)^2 + \frac{(1{,}09 \cdot X - X_o) \cdot 3600}{175 \cdot q_{н} \cdot \lambda \cdot T_o}}\right], \tag{4}$$

and when $X > 1{,}14$

$$N_o = 900 \cdot \frac{T_o}{3600} \cdot q_{н} \cdot \lambda \cdot \left[X - 1 + \sqrt{(1 - X)^2 + \frac{(X - 0{,}92 \cdot X_o - 0{,}08) \cdot 3600}{300 \cdot q_{н} \cdot \lambda \cdot T_o}}\right]. \tag{5}$$

where T_o – duration of the peak period, h;

X_o – the maximum degree of saturation, above which congested cycles will be expected. Calculated by formula

$$X_o = 0{,}67 + 0{,}001667 \cdot q_{н} \cdot t_z. \tag{6}$$

However, the calculation in this case will be correct only for the external overload occurring at the first stop line. And at the internal overload arising at the conditional second and third stop-lines, the calculations will not be correct, because the reference to the Brilon and Wu's formula in this case is conditional.

Statement of basic materials

In order to consider the process of occurrence of overloading at the intersection at one of the inputs, we should refer to Figures 1 and 2.

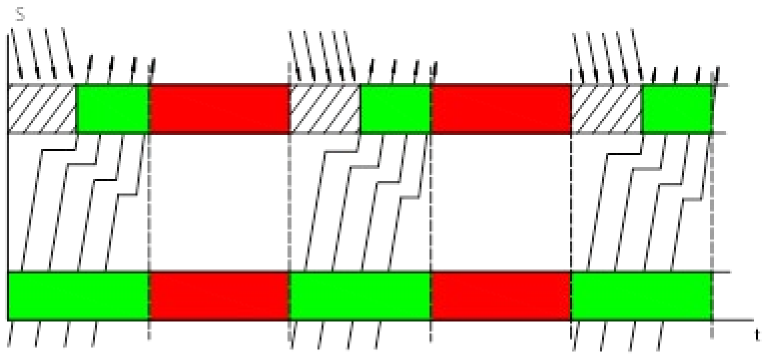

Figure 1 – t-S diagram of overcoming the first and conditional second stop-lines left-turn flow at the regulated intersection at lane load factor X<0,93

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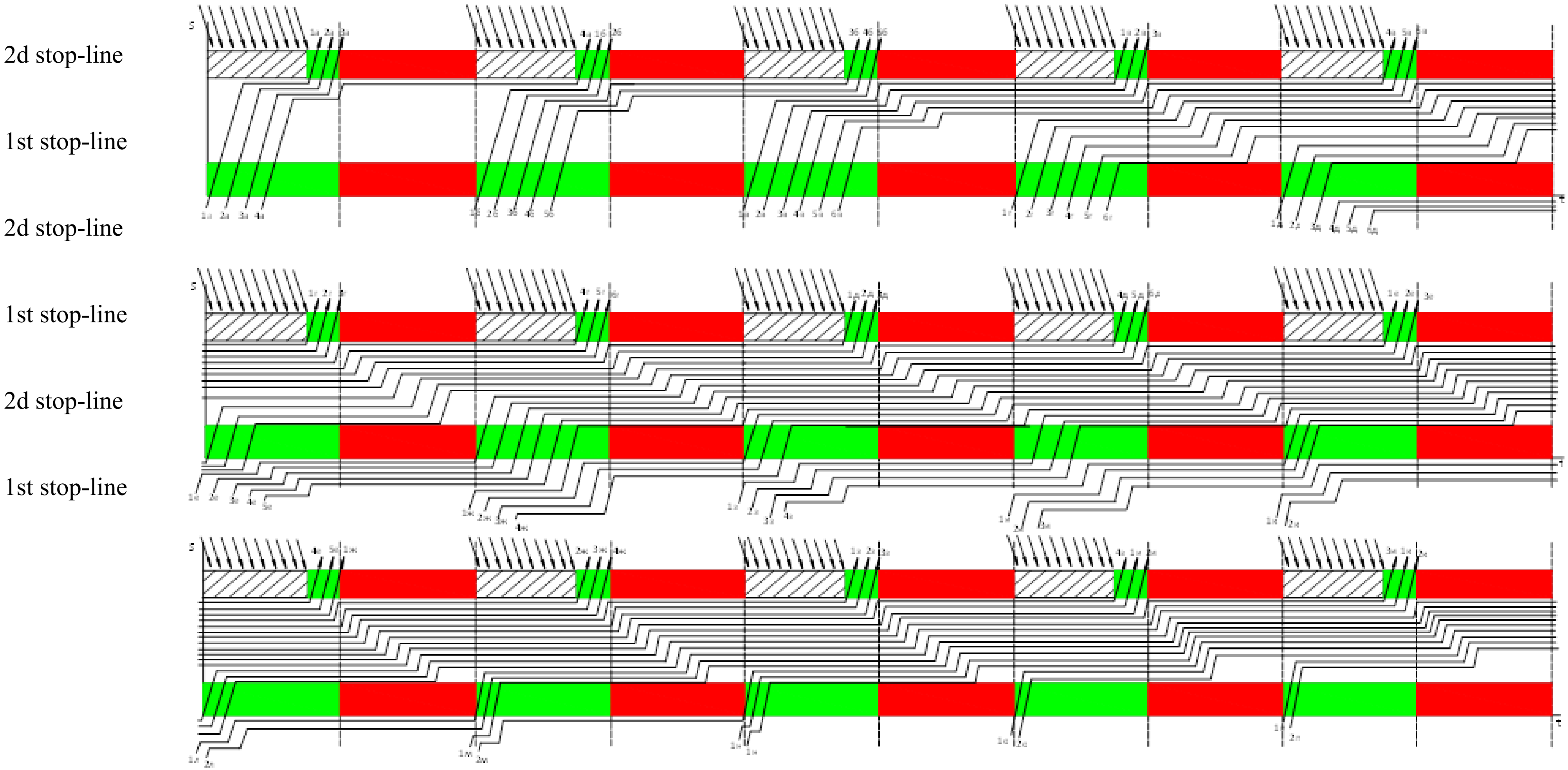

Figure 2 – t-S diagram of overcoming the first and conditional second stop-lines by left-turn traffic at a regulated intersection under under congestion conditions

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Figure 1 shows the t-S diagram of overcoming of the first and conditional second stop-lines by the left-turn flow at the regulated traffic light object with the lane load factor X<0,93 (the turning flow is considered, since it causes the most questions; in this particular case the conditional third stop-line is not considered, since it is assumed that by the time the "dissolution" of the queue at the conditional second stop-line begins, pedestrians will leave the intersection). This diagram shows that in each of the three traffic light cycles the number of vehicles arriving at the entrance of the intersection is equal to the number of vehicles leaving the intersection in the same traffic light cycle.

Figure 2 shows the process of queue growth at stop-lines, leading to congestion, and the moment of "dissolving" of the queue. It is conventionally assumed that in one traffic cycle the conditional second stop line can pass no more than three cars. In the first cycle the first stop line is four cars, and the conditional second – only three. Therefore, the fourth car remains for the second cycle. In the second cycle, the five cars arriving become in line behind the fourth car from the first cycle. In the second cycle, the fourth car from the first cycle, the first and second cars from the second cycle pass, and the third, fourth and fifth cars from the second cycle remain for the third cycle at the conditional second stop line until it is "overloaded". Figure 2 shows that already in the sixth cycle the cars arriving to the first stop line cannot cut it off. The queue does not have time to eliminate in cycles, so it will grow until the eighth cycle, and in the tenth cycle it will go down.

Figure 3 shows the shape of the distribution of the length of the queue of cars stopped in front of the first and conditional second stop-lines.

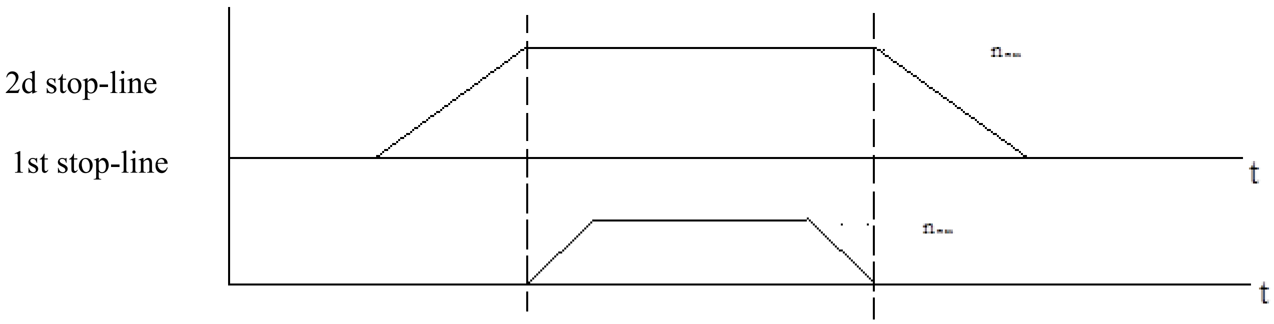

Figure 3 – The form of distribution of the number of cars (queue length), stopped before the first and conditional second stop lines at the controlled traffic light object during the overloading

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Conclusions

The total specific traffic delay during congestion will consist of the specific traffic delay at the first stop line, calculated by Brilon and Wu’s formula, and the specific traffic delay at the conditional second stop line, which still needs to be determined.

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2. Dauhulevich V.A. Models for calculating specific transport delays at a signalized intersection // Modern Engineering and Innovative Technologies, Iss. 20, Part 2. – Karlsruhe, Germany: Sergeieva&Co, 2022. – P. 21-25.

Аннотация. *Задержки (потери времени) транспорта из-за снижения скорости движения или вынужденных простоев на улично-дорожной сети можно отнести к экономическим потерям. В статье рассматривается процесс образования внутренних задержек транспорта при перегрузке.*

Ключевые слова: *регулируемые перекрестки, задержки транспорта, загрузка полосы движением, коэффициент насыщения, первая стоп-линия, условная вторая стоп-линия.*

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