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Calculation of Traffic Capacity of Signaled Intersections

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Abstract

In order to calculate traffic capacity of signaled intersections, it was suggested to apply an approach based on the concept of congestions. The paper states examples of traffic capacity calculation.

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Keywords: signaled intersections; traffic capacity; congestion

1. Introduction

Increase of traffic intensity leads to situations when it becomes impossible to provide a satisfactory level of traffic servicing with the help of only traffic light signaling means. Congestion at a section of the road traffic network with traffic signals is a situation when the average duration of the vehicle delay exceeds the length of the traffic signaling cycle [Kapitanov and Khilazhev (1986), Federal Road Agency (Rosavtodor) (2012)]. In this case, the queue length can increase, reaching the length of the road intersection. Further development of the road blocking paralyzes larger parts of the road network and disorganizes the traffic in whole.

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Congestions can be divided into systematic (stable) and occasional. The cause of occasional congestions can be different random factors, such as accidents or emergency situations. Systematic congestions are characterized by periodic repetition in time and stability in space. Such congestions occur in certain directions of movement at the same sections of the road traffic networks, during "rush hours", as a rule.

Basically, optimization of traffic control implies challenging of forecasting, recognition and elimination of pre-congestion situations, preventing road blocks, which requires exclusion of causes of traffic overloading by means of redistributing of traffic flows onto alternative routes. The traffic control system should promptly inform the drivers on possible traffic congestions and recommend bypass routes [Kravchenko (2013)].

2. Main text

2.1. Methods

Methods of traffic flows control in the situation of congestions can be divided into methods of on-line control and methods which are based on the input data on parameters of traffic flows referring to the time prior to the moment for which the impact is calculated. Input data of the latter methods can apply to any other "standard" situations. The method of control based on the analogue of the "library" of free traffic flows control applications can serve as an example [Kapitanov and Khilazhev (1986), Plotnikov (2010), Transportation Research Board, National Research Council (2000)]. For example, M-number of standard situations for the object was revealed in the result of field observations. Corresponding exposure is calculated for each such situation. The system measures different traffic flow parameters, and if these parameters are close to those of some standard set out of M-number situations, the system completes appropriate actions.

2.2. Examples

Let us consider an example of a simple intersection of two-way roads and multi-phase control of actions and characteristics of traffic flows.

Let us introduce the following variables: q_{ik} (intensity of i^{th} flow in the k^{th} phase), C_{ik} (congestion flow corresponding to the i^{th} flow), g_k (duration of enabling traffic signal k), l_{ik} (time loss per a cycle related to the traffic flow with the intensity q_{ik}), n (the number of control phases) (Fig. 1).

In accordance with the diagram of the queue relieving (Fig. 1), the driver spends some time on starting and acceleration under fully intensive enabling period after the green signal starts. After a few seconds, the intensity of queue relieving reaches its peak value and stabilizes (the flow of loading). Fig. 1 shows time interval revealing the effective duration of the green signal g, which is defined as the time interval during which cars move across the stop line (under piecewise-constant approximation of the output flow intensity).

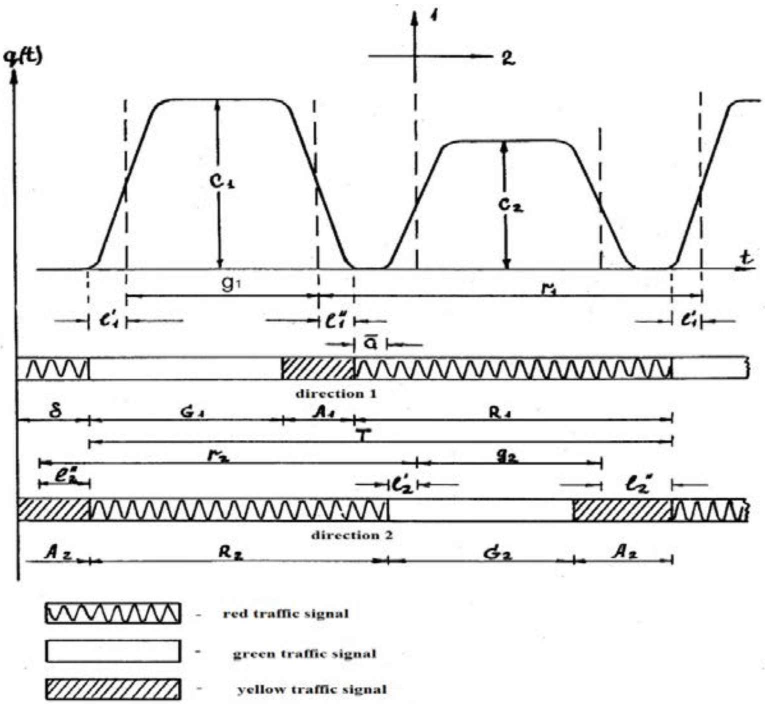

Fig. 1. A picture of controlling traffic signals of the intersection.

The time of the vehicle waiting in the queue does not exceed the duration of the cycle (no congestions), if the following conditions are satisfied:

$$\forall\ k: q_{ik} T \leq C_{ik} g_k$$

$$\sum_k (g_k + l_{ik}) = T \qquad (1)$$

$$g_{min} \leq g_k \leq g_{max},$$

$$T_{min} \leq T \leq T_{max},$$

where g_{max}, g_{min}, T_{min}, T_{max} are restrictions laid by the road traffic rules.

This system of inequalities (constraints) connects movement parameters (q, C) and control signals (T, g_k).

If an objective function is added and the optimization problem is solved under the above stated restrictions, then the values of control signals can be obtained.

If T and g_k are excluded from the system (1), we can get such a condition when there is no congestions at the intersection (if we want to find a condition under which there is no congestions, without solving the optimization problem every time, at that):

$$B_m \le T_{max}$$

$$1 - \sum_k A_{mk,k} > 0$$

$$\frac{q_{mk,k}}{C_{mk,k}} B_m \le g_{max}$$

$$A_{mk,k} = \frac{q_{mk,k}}{C_{mk,k}}$$

$$B_m = \frac{\sum_k l_{mk}}{1 - \sum_k A_{mk,k}} \tag{2}$$

where m_k is the number of flows (m) in the phase k, which corresponds to

$$A_{mk,k} = \max_i \frac{q_{ik,k}}{C_{ik,k}}$$

Violation of any condition means that the period of the vehicle stay in the queue exceeds the duration of the cycle, i.e. there is congestion at the intersection. An example:

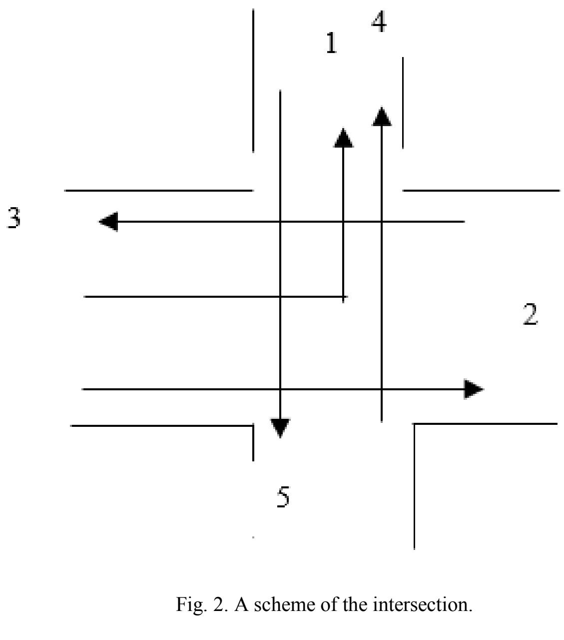

Fig. 2. A scheme of the intersection.

A condition of congestion absence at the intersection with traffic light signaling is defined as follows (Fig. 2).

Phase 1 (traffic flows 1, 2) $\frac{q_1}{C_1} \le \frac{q_2}{C_2}$ $m_1 = 2$ $A_{21,1} = \frac{q_2}{C_2}$

Phase 2 (traffic flow 3) $\frac{q_3}{C_3}$ $m_2 = 3$ $A_{32,2} = \frac{q_3}{C_3}$

Phase 3 (traffic flows 4, 5) $\frac{q_4}{C_4} \ge \frac{q_5}{C_5}$ $m_3 = 4$ $A_{43,3} = \frac{q_4}{C_4}$

Conditions determining traffic congestions are as follows:
$A_{21,1} + A_{32,2} + A_{43,3} \ge 1$ — congestion at the intersection
$A_{21,1} + A_{32,2} + A_{43,3} < 1$ — no congestions.
The system (2) can be applied to define the concept of "traffic capacity of a signaled intersection”.
A traffic capacity of the intersection implies a set of vectors with the physical dimension k (a number of phases); their projections onto coordinate axes equal the intensity $q_{m_k,k}$ and satisfy the following condition at the same time:

$$\sqrt{\sum_k q_{m_k,k}^2} \to \max.$$

An example:

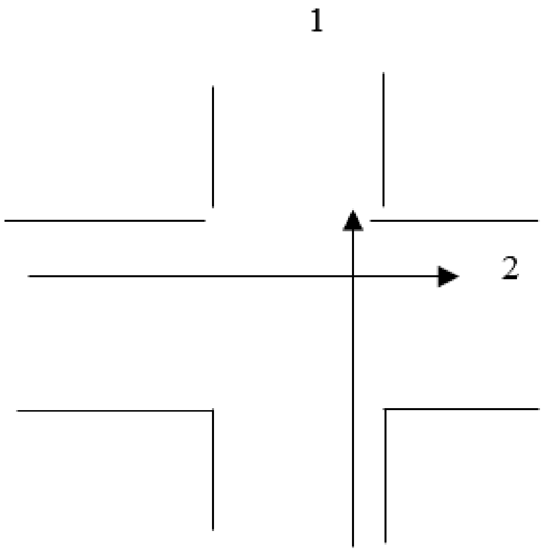

Fig. 3. A scheme of a simple intersection.

Let us consider an intersection with two-phase signaling control shown in Fig. 3. Let us assume that, in this case, there are no restrictions on duration of the cycle and no limits on effective duration of enabling signals, i.e.:

$$g_{\max} = \infty,$$

$$T_{\max} = \infty$$

In this case, the traffic capacity of the intersection, i.e. the vector $q = (\overline{q_1}, \overline{q_2})$, is determined by the following equation (to simplify the task, the loading flows are assumed to equal 1):

$$1 - \overline{q_1} - \overline{q_2} > 0$$

$$\sqrt{\overline{q_1}^2 + \overline{q_2}^2} \to \max$$

Fig. 4 states solution of this task:

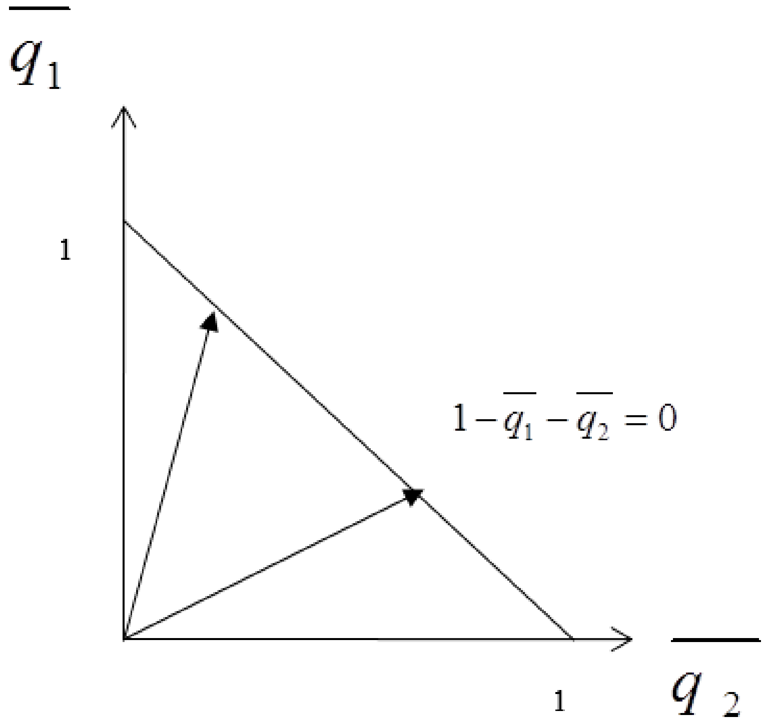

Fig. 4. Graphic illustration of intersection traffic capacity.

The traffic capacity of the considered intersection is summed up of a set of vectors with the beginning at the zero point and the ending on the line connecting the points with unit coordinates on the axes.

3. Conclusion

Thus, it is proposed to use the above stated approach based on the concept of congestions to calculate the traffic capacity of intersections and roads with traffic light regulation.

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