Assessment of the impact of capital construction on the adjacent street-road network with traffic at unregulated intersections

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Abstract. The article discusses the problems of assessing the influence of centers of gravity on the adjacent street-road networks in the process of their functioning, expansion or reprofiling. The paper shows the main models for estimating the throughput of unregulated intersections proposed in the domestic and foreign literature. The author gives sequence of calculating the transport demand transforming into the intensity of the traffic flow on the road network. Moreover, the study proposes recommendations on assessing the level of traffic service and load factor based on transport demand and throughput, adjacent street-road network.

1. Introduction
The throughput of the street-road network (SRN) is the main criterion for assessing its potential capabilities, i.e. the size of the transport supply, formed both in its individual sections, and on the scale of the city (city district). The problems of assessing the throughput of roads and its elements are widely studied and presented in the domestic and foreign literature [1-7, etc.].

Along with the transport supply, one of the main criteria for assessing the effectiveness of the functioning of the SRN is the ratio of transport demand, transforming into the intensity of individual transport on the SRN and the transport supply, expressed in SRN capacity. This ratio is called the SRN load level and is expressed by the load factor. For normal driving conditions, such a system should meet the condition of balance i.e. transport demand should not exceed transport supply. Thus, it should be concluded that the effectiveness of the functioning of the SRN as a whole will mainly depend on the traffic organization at its individual nodes (intersections).

2. The main part
According to federal law No. 433 of December 29, 2017, “On the Organization of Road Traffic in the Russian Federation and on Amending Certain Legislative Acts of the Russian Federation”, the following provisions apply in the Russian Federation today:
• the need to develop a plan during the construction or reconstruction of capital construction objects (CCO) in relation to the network of roads and (or) their sections adjacent to the indicated CCO;
the need to prepare engineering survey materials, research results of existing and predicted traffic parameters, and statistical information;
- requirements for ensuring the effectiveness of traffic organization, which must be taken into account when placing a CCO in accordance with the legislation on urban development. CCO placement in violation of traffic organization performance requirements is not allowed;
- the need to calculate the capacity (number of parking spaces) of public parking lots is determined in accordance with the standards of urban planning;
- the need to develop a plan when arranging vehicle entry into and out of public parking, and vehicle movement inside a public parking lot.

The level of traffic service is a concept that has been firmly entrenched in domestic regulatory documents relatively recently, and this is primarily due to the development of motorization, an increase in the number of types of vehicles and, accordingly, the need for traffic organization with a very wide range of factors and traffic conditions. This concept is a derivative of the basic characteristics of the functioning of SRN elements and, above all, intersections. These characteristics include the load coefficient (level) \( z = N/P \), where \( N \) is the traffic intensity, vehicle/h, \( P \) is the actual (practical) throughput, vehicle/h.

The model for estimating the throughput of unregulated intersections is represented by the expression:

\[
P_p = N_{gl}(A \cdot e^{-\beta_1 \cdot \gamma \cdot \Delta t_{gr}} + B \cdot e^{-\beta_2 \cdot \gamma \cdot \Delta t_{gr}} + C \cdot e^{-\beta_3 \cdot \gamma \cdot \Delta t_{gr}})
\]

where \( N_{gl} \) – traffic on the main road, vehicle/h; \( \gamma = N_{gl}/3600 \); \( A \) – coefficient characterizing freely moving cars; \( B \) – coefficient characterizing a partially connected part of the flow of cars; \( C \) - coefficient characterizing the connected part of the flow of cars; \( A = \epsilon_m - \epsilon_p \) – for uphill sections; \( \epsilon_m \) - coefficient taking into account the number of slowly moving cars in the flow; \( \epsilon_p \) - coefficient taking into account the steepness of the slope and the length of the elevation; \( \Delta t_{gr} \) – boundary interval accepted by the driver; \( \delta t \) - interval between exits of cars from the queue on the secondary road, sec; \( \beta_1, \beta_2, \beta_3 \) – coefficients characterizing traffic flow density; \( A+B+C = 1 \).

Thus, given the transport demand, transforming into the intensity of individual transport, which can be calculated by the expression:

\[
N_{HT/\text{vac}} = E_{\text{num}} \cdot \frac{d_{HT}}{P_{HT}} \cdot k_{CH}
\]

where \( d_{HT} \) – the proportion of visitors with individual cars per hour; \( P_{HT} \)– average number of passengers, people.; \( k_{cn} \) – daily unevenness coefficient for the considered hour; \( E_{CHMT} \) – transport demand for local nod, corr/day.

The load factor \( z \) for unregulated intersections will look like this:

\[
z = \frac{E_{CHMT} \cdot d_{HT} \cdot k_{cn}}{N_{gl}(A \cdot e^{-\beta_1 \cdot \gamma \cdot \Delta t_{gr}} + B \cdot e^{-\beta_2 \cdot \gamma \cdot \Delta t_{gr}} + C \cdot e^{-\beta_3 \cdot \gamma \cdot \Delta t_{gr}})}
\]

In general, we should note that the 2.32 model is highly saturated with factors that take into account the presence of connected parts of the traffic flow “bundles”, slopes, flow density, etc., which, according to the author, is a reflection of the intervals between vehicles in the main stream. Depending on these intervals, the speed of the main flow, as well as the time intervals between vehicles in the secondary flow, the throughput of the secondary direction at an unregulated intersection will differ. Thus, a technique that takes into account mainly the listed factors is presented in [6, 7, 8].

The driver decides to enter an unregulated intersection while approaching the intersection and moving in a secondary direction, which depends on the size of the time interval between two consecutive vehicles in the main direction. If the driver considers one of these intervals acceptable, he starts moving, but if the interval seems too small to him, he will wait for an acceptable interval. If the driver waits too
long, then it may turn out that in the end, for an acceptable one, he will count an interval that will be less than one of those that he has already missed.

The time interval that the driver needs to start moving in a secondary direction is called the boundary interval. At this stage, when calculating, it should be taken into account that at all approaches to the intersection, each group of traffic (left, straight and right) carries out movement along a designated lane, so far without taking into account the real organization of traffic and the number of lanes at the approaches (Figure 1). The principle of movement at an unregulated intersection in accordance with the traffic rules and rankings is that the lower the rank value, the higher the priority for the passage crossing the traffic flow.

![Figure 1. Scheme of movement at an unregulated intersection.](image)

For example, flows of the first rank are not inferior to anyone, as a rule, they move along the road indicated by the sign 2.1 “Main road” in the forward or right-handed direction. The second rank is forced to give way to the first (from the main direction to the left and from the secondary to the right). The third rank implies passage directly from the secondary direction and is forced to give way to the first and second rank. The fourth rank (to the left from the secondary direction) gives way to everyone (1st, 2nd and 3rd rank), its throughput is the lowest.

The throughput of first-rank flows under ideal conditions (the absence of left and right turns, parked vehicles on the far right lane, longitudinal curves and curves in the plan, etc.) can be equated to an ideal saturation stream (approximately 1900 vehicles/h). When calculating the capacity of flows of the first rank (from the main direction to the right, in addition to the listed coefficients, we use coefficients that take into account the presence of pedestrian traffic, public transport stops, parking on the far right lane).

The throughput of flows of the second rank is estimated by the basic throughput, which is calculated for all ranks other than the first (2, 3 and 4 ranks). It should be noted that the basic throughput takes into account the influence of flows of the first rank only and for this reason the bandwidth of the flows of the second rank is equal to their basic throughput. The calculation is carried out by the expression:

$$G_i = \frac{3600}{t_f} e^{-\frac{q_p}{3600}\left(t_g - \frac{t_f}{2}\right)}$$

where $G_i$ – basic throughput of the secondary flow $i$, vehicle/h; $q_p$ – the intensity of the priority direction of the first rank, which conflicts with the considered one, vehicle/h; $t_g$ – the average boundary interval, sec; $t_f$ – average interval, sec.

With increasing traffic density, the average boundary interval decreases. The average boundary interval is taken on the basis of field studies of the most common cases at unregulated intersections.
To determine the throughput of a flow of 3rd rank, it is necessary to determine the likelihood that the flow of 2nd rank will move without jams:

\[ p = 1 - \frac{N}{c} \]  

(5)

where \( p \) – the probability of unhindered movement of flows of the 2nd and 3rd ranks; \( N \) – the intensity of the movement of the flow, units/h; \( c \) – throughput of the considered flow, vehicle/h.

The probability of an unhindered movement of a flow of rank 2 is calculated for each approach. The capacity of the 3rd rank flow is determined based on the formula:

\[ c_3 = \prod_{i=1}^{n} p_{02} G_3 \]  

(6)

where \( G_3 \) – 3rd rank basic flow throughput, units / h;

The capacity of the 4th rank flow is determined based on the formula:

\[ c_4 = \prod_{i=1}^{n} p_{02} \prod_{j=1}^{m} p_{03j} G_4 \]  

(7)

where \( \prod_{i=1}^{n} p_{02} \prod_{j=1}^{m} p_{03j} \) – the product of the probabilities of the unhindered movement of all flows of the 2nd and 3rd rank, which are inferior to the considered flow of the 4th rank.

In the methodology for assessing the throughput of unregulated intersections, it is important to remember that the throughput of each direction is calculated taking into account the fact that each direction (traffic flow) moves along a dedicated lane. It does not take into account mutual interference (delays) resulting from combining flows of different ranks into one or more physical bands on the way. As a rule, secondary approaches have no more than one lane on the approach, and the main no more than two (Figure 2). A particular case of identifying the effectiveness of an unregulated intersection is to determine the throughput of a mixed lane (Figure 3).
Figure 2. Possible options for organizing traffic at an unregulated intersection.

Figure 3. Mixed lane at unregulated intersection.

The mixed bandwidth is determined by the following formula:

\[
c = \frac{1}{\sum_{i=1}^{n} \frac{a_i}{c_i}}
\]

where \( c \) – throughput of the mixed lane, units/h; \( a_i \) – is the fraction of the i-th flow in the sum of all n flows in the considered lane; \( c_i \) – hroughput of the i-th direction, units / h.

Thus, given (4) - (8), the load factor of the i-th flow can be represented by the expression:
\[ z = \sum_{i=1}^{n} \frac{E_{iun}}{P_{iun}} \cdot \frac{d_{iun}}{P_{iun}} \cdot k_{e}^{v6} \cdot k_{d} \]

where \( N_{i} \) – the intensity of the i-th direction of the traffic flow in the movement group, vehicle/h; \( q_{p} \) – the traffic intensity of rank 1, which conflicts with the direction of movement, vehicles/h; \( k_{d} \) - coefficient taking into account the share of traffic flow distributed between intersections; \( k_{e}^{v6} \) - coefficient of daily unevenness in descending order; \( n \) – number of traffic flows in a traffic group; \( t_{s} \) – is the average boundary interval, sec; \( t_{f} \) – is the average interval of succession, sec; \( N_{02,j} \) – is the traffic intensity of the second rank, which conflicts with the direction of movement, vehicle/h (in the absence it is excluded); \( N_{03,j} \) – is the traffic intensity of the third rank, which conflicts with the direction of movement, vehicle/h (in the absence it is excluded); \( c_{02,j} \) and \( c_{03,j} \) - throughput of the traffic flow of the second and third ranks, respectively, conflicting with the direction of movement; \( m \) – the number of traffic flows of the second and third ranks, respectively, conflicting with the direction of movement.

The value of the impact of the CCO on the adjacent SRN in the case of re-profiling of existing or commissioning of new ones should be estimated on the basis of mathematical models relying, on the one hand, on the methodological recommendations of the industry document for assessing the capacity of roads, and on the other, on transport demand arising to this CCO.

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