Capacity of merging areas of multi-lane roads with two-lane entrance ramps

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Abstract. The discrepancy between transport demand and supply in the largest cities of the Russian Federation determines the need to create urban high-speed roads on their territory. Currently, there is no data on the capacity of sections of multi-lane road junctions with two-lane exit ramps, taking into account traffic conditions in large and major cities of Russia. The article presents the results of studies of the throughput of such sections of interfaces. The research was carried out using simulation methods after calibration of the model taking into account traffic conditions on the roads of the largest cities of the Russian Federation. The obtained research results are recommended for a reasonable assignment of the type of conjugation of two-lane exits with multi-lane highways on the territory of large and largest cities in Russia.

1. Introduction

Sections for merging travel paths of highways and urban high-speed roads are considered to be one of the main sources of increased accident number and congestion on highways (Hounsell and McDonald, 1992; Evans et al., 2001, J. Lu, P. Liu, B. Behzadi, 2007, J.A. Barria, S. Thajchayapong, 2011, M.W. Levin, S.D. Boyles, 2016). Despite a significant number of works devoted to this topic, there has not been developed until now a unified approach to determining the throughput capacity of highway merging sections. The concept of "confluence" of traffic flows is understood by most researchers as an elementary section consisting of two traffic lanes, within which the confluence of two traffic flows (the basic and the secondary) takes place. When multi-lane ramps are merged with the basic segment of a highway, a complex confluence section is formed consisting of several elementary sections for the confluence of traffic flows (Fig. 1), within which cars perform changeover maneuvers related both to the need for a mandatory lane change due to changing road conditions (MLC maneuver), and for reasons related to the desire of a car driver to move in a certain lane (DLC maneuver).
Figure 1. Scheme for determining the throughput capacity of a travel path merging section: 1 - an elementary merging section, 2 - a complex merging section, 3 - a traffic flow merging section.

The variety of schemes representing the mutual arrangement of elementary sections for merging traffic flows and the characteristics of the drivers’ behaviour (national peculiarities of legislative regulation, the mentality of drivers, the composition of the traffic flow) does not allow to develop until now uniform recommendations for determining the throughput capacity of traffic flow merging sections, which is noted in a number of works devoted to studies of the throughput capacity of traffic flow merging sections (J. Shen, W. Li, F. Qiu, S. Zheng, 2015). This paper presents the results of studies devoted to the throughput capacity of traffic flow merging sections of highways with two-lane ramps, taking into account traffic conditions on the territory of the Russian Federation.

2. Method of studies devoted to the throughput capacity of merging sections of multi-lane roads with two-lane ramps

Traditionally, the Poisson distribution and the exponential distribution related with it inversely have been most widely used to determine the throughput capacity of traffic flow merging sections (Gross, D. and Harris, C, 1998). The Poisson distribution is most valid if a certain event constantly occurs with a sufficiently high probability; therefore, this distribution corresponds to the nature of the movement of congested traffic flows along road sections with heavy traffic (in conditions of continuous traffic, without traffic control devices). With the distribution of the car following distances according to Poisson’s law, the distribution of the time intervals between the cars will be continuous exponential. Then we can write the probability density function for occurrence of intervals in the flow (1):

\[ P = \lambda e^{-\lambda x} \]  

Where \( \lambda \) – distribution function parameter

The exponential distribution does not give satisfactory results for convergence of empirical data and theoretical values in the conditions of car traffic “in columns”, which can be observed when cars move along two-lane highways in a mode close to the throughput capacity mode. The exponential distribution shows satisfactory convergence only when driving with some margin of capacity along two-lane roads, or along multi-lane roads where overtaking is possible.

Assuming multiple entries of secondary direction cars into the basic traffic flow with a sufficient time interval to complete such a maneuver, the ratio (2) could be written:

\[ N = M \times \frac{\frac{M \times \Delta T_{GP}}{3600}}{1 - e^{\frac{-M \times \Delta T_{GP}}{3600}}} \]  

Where

\( M \) – Traffic intensity along the lane adjacent to the confluence area, reduced number of cars / hour;
$N_c$ — Throughput capacity of the secondary movement direction, reduced number of cars / hour;
$\Delta T_{trp}$ — Time interval used in the interaction of traffic flows, depending on road conditions, s;

This method of determining the throughput capacity of the confluence sections gives good convergence with the results of observations in the study of elementary sections for traffic flow confluence on single-lane speed transition ramps (for example, Drew, 1967; Darzentas, 1981).

Throughput capacity investigation for more complex merging sections, for example, merging sections of two-lane ramps, is associated with the study of confluence sections consisting of several elementary sections. The close relative position of the elementary merging sections determines their significant mutual influence. Therefore, there is not enough data on the throughput capacity of elementary merging sections to assess the throughput capacity of complex confluence sections; it is necessary to simulate their joint work, taking into account the performance of DLC maneuvers by cars.

Taking into account the limited sampling capabilities concerning sections for merging two-lane ramps with highways and high-speed township roads in the territory of the largest cities of Russia, studies of the throughput capacity of sections for merging travel paths were carried out using simulation methods based on the single-car movement models developed by Wiedemann (1974) and lane change model developed by Sparmann (1978), allowing to take into account the joint work of elementary merging sections (hereinafter SW-model).

Before carrying out a numerical experiment using the simulation method, the SW-model was calibrated taking into account the traffic conditions on multi-lane roads in cities of the Russian Federation. The model was calibrated on the basis of comparing the throughput capacity values of the merging sections obtained from the calculation using the SW-model (Fig. 2, SW-model) and the throughput capacity values of the merging sections obtained by the calculation according to formula (2) using the data on the distribution of boundary following distances ($\Delta T_{trp}$) for cars on elementary merging sections (Fig. 3), which were obtained by the authors within the intersections at different levels of the roads in the largest cities of the Russian Federation: Moscow, St. Petersburg, Yekaterinburg and Novosibirsk in 2018 (Kostsov, 2018). The length of the speed transitional lane (the section of merging traffic flows) when carrying out calibration calculations is assumed to be 260m. A good convergence of the results obtained by the calculation method according to (2) and using the SW model was obtained due to the results of calibration calculations.

**Figure 2.** Traffic gaps of cars at the acceptance rate of 50% and 85% in confluence zones of traffic flows.
3. Investigation of the capacity of the sections of mergings of multi-lane roads with two-lane ramps by the method of simulation

In order to study the throughput capacity of the sections for merging multi-lane roads with two-lane ramps, a classification of traffic flow confluence sections was developed, which is shown in Fig. 4. The type of speed transition lanes according to a parallel scheme is adopted. The lengths of the ramp sections of the transitional speed lanes, and the full-width section lengths are taken in accordance with the recommended values specified in the regulatory documents in force in the Russian Federation (SP 34.13330.2012). The values of the main geometrical parameters adopted in the research are given in Table 1.

| L, L₁, m | L₀, L₀₁, m | L₂, m | Slope, % |
|----------|------------|-------|----------|
| 180      | 80         | 60    | 0        |

A numerical experiment was carried out for each merging section type for four-lane, six-lane and eight-lane highways within the range of possible traffic intensities on the base segment (N₀).
4. Results and discussion
Statistical processing of the experimental results obtained by means of simulation modelling made it possible to obtain data on the throughput capacity of two-lane ramps depending on the car movement intensity in the basic direction and the type of merging section for two-lane ramps upon traffic conditions on the territory of the Russian Federation. The throughput capacity of the merging section made according to type (a) does not exceed 2200 reduced number of cars / hour. Arrangement of two-lane merging by type (a) is recommended in narrow conditions of construction and reconstruction, when it is impossible to place other types of two-lane ramp merging with a highway.
Figure 5. Simulation results - curves for the dependence of the throughput capacity of two-lane ramps on the traffic intensity in basic direction: (a) for 4-lane roads, (b) for 6-lane roads, (c) for 8-lane roads.

The arrangement of adjoining roads according to types (b) and (c) allows the merging of traffic flows without increasing the number of lanes in the basic direction and is recommended for use when the ratio of traffic intensities does not exceed those indicated in Fig. 5. When the ratio of traffic intensities does not allow the arrangement of adjoining roads of type (b) and (c), it is necessary to use adjoining roads of type (d). If the intensity ratio does not allow the type (d) merging to arrange, it is recommended to use the type (f) merging with the arrangement of two additional lanes in the main direction.

5. Resume
Based on the studies carried out, the dependences of the throughput capacity of two-lane ramps on the traffic intensity in the basic direction were established, which are shown in Fig. 5. The research results can be extended to the mergings of two-lane ramps in large cities and metropolises of Russia.

6. Conclusion
The results of studies for two-lane ramps presented in the paper can be used to the throughput capacity calculate the capacity of multi-lane highways at the merging ramps of two-lane ramps.

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