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Dimensioning of the Speed-Transition Lanes at the Entering Ramps on the Motorway and Urban Road Intersections

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Abstract

Urban roads and streets - an important part of the urban economy. Highways and street and road network of the city form its planning structure. This is the most stable element of urban structure. Urban development is inextricably linked with the city's road network development. This paper analyses and presents, in a concise form, an actual methodology and some insights concerning the defining of the parameters, dimensioning and forming of the junction ramps in the entering zones (acceleration zones) of the same into motorways, highways and main urban streets from the flow capacity point of view.*

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1. Introduction

Urban roads and streets - an important part of the urban economy. The construction and exploitation of the road knots conditions their dimensioning and formation so as to be able to naturally, most olptimally and functionally react to movement, correspondence and characteristics of the traffic flows in view of providing for security, comfort and maximum flow capacity. The complexity of the problems concerning the designing of the junctions starts at the definition of the respective traffic strain, the basic design and construction elements until the spatial formation. It is

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even more difficult to react to such conditions, because they imply massive accidental phenomena or features standing in “stochastic” relations (stachastics laws) defined by statistic researches.

Therefore, the junctions (intersections) are one of the most complex engineering constructions, both for non-urban and even more for the urban streets. In this view there are still dilemmas and diverse methodological and empirical procedures in defining certain parameters in dimensioning certain functional elements for the formation and optimization of the knot. According to this, it is still actual to “precise” some parameters, especially concerning the speed-changing elements (lanes entering the basic flows) as most critical zones in the knot. The most complex problem is surely the optimization of the knots [1-9].

2. Speed changing entering lanes

The application of entering lanes (acceleration – adaptation of the speed upon changing of lanes) creates more favourable conditions for movement and flow capacity. But the absence of some factors upon the dimensioning of certain functional elements of such lanes, leads to their becoming inadequate for their own functional importance. The operation (process) of their entering into the main traffic flows (on the highway) is more complex than the leaving operation, because, in order to connect the traffic flows, there is a possibility of greater collisions if the entering lanes are not properly dimensioned and formed. The capacity of entering depends on the intensity of traffic on the main direction and on the intensity of the flow that is entering, that is, on the probability that the temporary gaps (critical intervals) among the vehicles of the main flow.

In the Macedonian and foreign literature, the regulaitons and the standards (technical regulations) there are recomendations for the establishment of dimensions of certain functional parts of the entering lanes on the state roads and highways. It is necessary to note that many recommendations, regulaitons and standards had empirical character, and the formulas for dimensioning have an “unfinished” form. Such recommendations are applied by the designers as “models”, by tables and charts.

This paper gives, both theoretically and scientifically, a precision of the methodology of dimensioning of the speed-changing entering lanes.

The essence of the methodology in the dimensioning of such lanes consists of their differenciation per functional zones (sections). It should be objectively treated by three functional parts (dealt with differently in the original ltierature).

The functional parts of the lane are as follows:

- L1 –manoeuvering part with expectance of a free interval between the vehicles of the main flow
- L2 –speed increase section (acceleration) until the amount of the speed of the basic traffic flow
- L3 –entering section (lane changing)

The actual problems are: the estimation of the amount of decrease of the speed on the basic road direction and, on the basis thereof, recommending the provision of the necessary speed of movement, precision of the mdoels for the determination of the geometric dimensions of the elements of the entering lane as per the functional parts (zones).

The traffic flow process consists of the following concerning the entering process: $V_0<V_a$; $V \leq V_0$; limiting critical itnerval (t_k). The safe itnerval between the first and the second entering vehicle thereby consists of the following:

$$t_1 = \left(t_p + t_t\right) + \left(L_a + L_o\right)/V_a + \left(S_0 - S_1\right)/V_a \quad [\text{sec}] \tag{1}$$

where:

$L_p = \left(t_p + t_t\right)V_2$; $t_p + t_t$ - time of the driver’s reaction to the entering lane

L_a+L_0 - static volume of the vehicle and minimal distance between the vehicles upon braking (3 to 5 m)

S_0-S_1- difference in braking length of the front and back vehicle (the vehicle of the main flow and the one on the entering lane).

It is usually taken that $t_p + t_t$ =1 sec, which gives the following:

$$t_1 = 1 + (L_a + L_0)/V + (S_0 - S_1)/V_a \tag{2}$$

The measures S_0 i S_1 are obtained according to the following formulas:

$$S_0 = \frac{k_0 \cdot V_a^2}{2 \cdot g \cdot (f_t \pm i_n)}; \quad S_1 = \frac{k_1 \cdot V_a^2}{2 \cdot g \cdot (f_t \pm i_n)}; \text{ za } V_a \text{ [m/s]}$$

where:

k_0 are k_1- coefficients of exploitation conditions of braking of the front and the back vehicle ($k=0.7 \div 1.4$), for urban conditions k=0.7, in other cases k=1.4 or it can be determined as per certin formulas [4]
f_t- tangental friction coefficient (0.3-0.7) for dry and wet pavement
i_n- longitudinal inclination of the road

By changing for S_0 and S_1 in (2) we obtain as follows:

$$t_1 = 1 + \frac{(L_a + L_0) \cdot 3.6}{V_a} + \frac{(k_0 - k_1) \cdot V^2}{254 \cdot (f_t \pm i_n)}; \; V_a \text{ (km/h)} \tag{3}$$

Draft it is evident that the Δt dimension remains in order to stop the second vehicle from the full capacity of the limiting interval (t_k) :

$$\Delta t = t_k - \left[2 \cdot (t_p - t_t) + 2 \cdot \frac{L_a + L_0}{V_a} + \frac{S_0 - S_1}{V_a}\right] \quad \text{wheree V (m/s)} \tag{4}$$

As the second vehicle decelerates we obtain:

$$S_2 - S_1 = \frac{b \cdot \Delta t^2}{2}; \text{ where \{to b [m/s}^2\text{] deceleration} \tag{5}$$

$$b = g \cdot (f_t \pm i_n)$$

(4) and (5) yields the following:

$$\frac{k_2 \cdot V_2^2 - k_0 \cdot V_0^2}{254 \cdot (f_t \pm i_n)} = \frac{b \cdot \Delta t^2}{2}, \text{ for V (km/h)} \tag{6}$$

This formula gives the velocity V_2

$$V_2 = \frac{1}{\sqrt{k_2}} \sqrt{k_0 V_0^2 + \left[127 \cdot (f_t \pm i_n) \Delta t^2\right]^2} \tag{7}$$

$$\text{for } \Delta t \le 0; \quad V_2 = V_0 \cdot \sqrt{\frac{k_0}{k_2}} \tag{8}$$

The expression (4) gives the necessary dimension of the time interval of Δt, in which the basic flow vehicles move with the constant velocity of V_a:

$$\Delta t = 2(t_p + t_t) + \frac{2L_0 + L_a}{V_a} \cdot 3.6 + \frac{(k_0 - k_1)V_a}{72(f_t \pm i_n)} + \frac{V_a\sqrt{k_2 - k_0}}{36(f_t \pm i_n)} \tag{9}$$

For example, in the conditions of: i_n=0; $2L_0$+L_a=10.5m; k_2-k_0=1.4; V_a20 m/s we obtain $\Delta t = 7.8\,s$

The length of the L_1 section is the most stochastic one and it has not yet bees exactly solved. It is most frequently treated as the only one with L_2 by using the interval of t_k=7-15 sec. But, realistically, that part L_1 should be equal to the product of the velocity of the vehicle V_c and the necessary time interval ($L_1 = V_c \cdot t_k$)

The average time of expectancy of a free interval of entering into the main flow is established according to the following formula:

$$t_{ks} == \int_0^{\Delta t} t \cdot f(t)dt \Big/ \int_0^{\infty} t \cdot f(t)dt \tag{10}$$

According to E. M. Lobanov, the distribution of the itnervals among the vehicles in the main flow is according to the exponential law:

$f(t) = \lambda e^{-\lambda t}$ which finally leads to the following:

$$t_{ks} = \frac{e^{\lambda t - \lambda\Delta t - 1}}{\lambda} \tag{11}$$

where $\lambda = \frac{M}{3600}$; (M- scope of the traffic on the main flow per hour)

The possibility of incurrence of a temporal gap of t_k in one traffic flow of M can be expressed by the Poisson's distribution in the following form:

$$P(t) = e^{-m}\frac{m^x}{x_i}\text{; where } m = \frac{Mt}{3600} \tag{12}$$

for x=o we obtain: $P(t) = e^{-m} = e^{-\frac{Mt}{3600}} = e^{-m_0 t}$; where e $m_0 = \frac{M}{3600}$

The frequency of the time gaps in the traffic flow in the interval from t_i to t_{i+1} is determined as per the following formula:

$$U(t) = k\left(e^{-m_0 t_i} - e^{-m_0 t_{i+1}}\right)\text{; (k- number of intervals)} \tag{13}$$

The maximum number of vehicles that can be included intot he main flow is as follows:

$M_{max} = \frac{M_1 t_k}{e^x - 1}$; where M_1 is the main flow, and $\alpha = \frac{M_1 t_k}{3600}$

Simplified empirical formulas according to [1] and [2]:

$$L_1 = \frac{0.75V_a^2 - V_r^2}{254(f_t \pm i_n)} \tag{14}$$

$$L_1 = \frac{0.75V_a^2}{3.6} t_k \text{ ; } t_k\text{=7-15 sec} \tag{15}$$

By using the formulas 8, and 11 it is possible to determine, for a given level of deceleration of the basic flow, the length of L_1 (expectancy of a favourable interval). On the perfect traffic knots it is not recommended to decrease the velocity of the basic traffic flow.

Upon the creation of a favourable gap interval in the basic flow, the vehicle in the entering lane accelerates in the section L_2 until the necessary velocity of V_a.

The length of L_2 is determined as according to the following formula:

$$L_2 = \frac{V_a^2 - V_c^2}{2a} = \frac{V_a^2 - V_c^2}{26a} \text{ ; } a = \frac{g(D \pm i_n)}{\delta} \text{ ; } \quad (a=0.8\text{-}1.2 \text{ m/s}^2;\ \delta=1.05\text{-}1.06) \tag{16}$$

D- dynamic factor of the vehicle

For the determination of the transitory section of L_3, the starting point is the supposal that the trajectory of the vehicle is according to fig. 1 (a and b)

The moving trajectory of the vehicles upon the changing of a lane of movement consists of two opposite curves (S-curve) with a changeable radius (fig. 1[a]) or by arcs (fig. 1[b]).

The curves with a transitory clotoid will have the parameter of $A^2 = RL = V^3 / S_R$ that is $A^2 = V^3 / (46.656 \cdot S_R)$; S_R- radial impact [m/s^3]

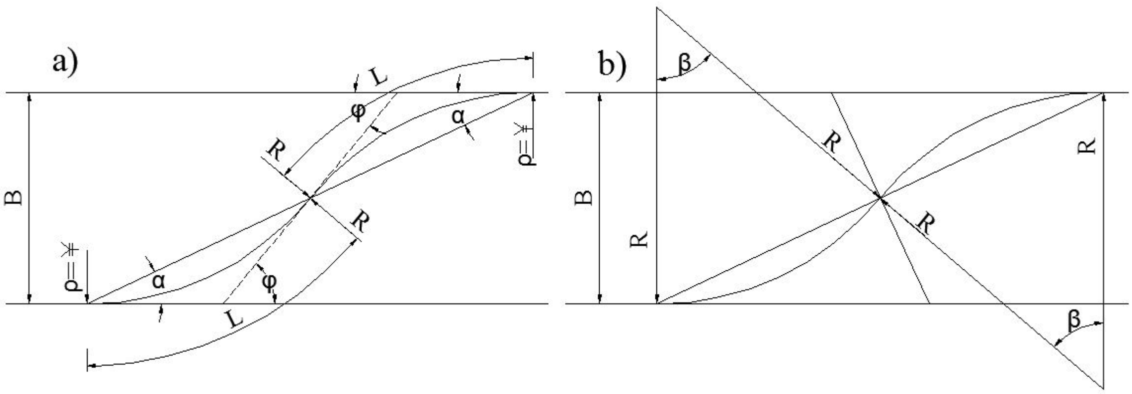

Fig. 1. (a and b). Vehicle move trajectory

As the turning angle is also small (4^0 to 5^0) we have:

$$tg\alpha = sin\alpha \approx \alpha \approx \varphi = \frac{B}{2L} \text{ i } L = 2R\varphi \text{ sledi:}$$

$$L = \frac{V^3}{46.656}\sqrt{\frac{B}{S_R}} \tag{17}$$

The length of L_3=2L gives the following:

$$L_3 = \frac{2V^3}{46.656}\sqrt{\frac{B}{S_R}}\text{; } S_R=(0.3\text{-}0.8)\ m/s^3 \tag{18}$$

The minimal radius of the curve is determined as per the known formula:

$$R_{min} = \frac{V^2}{127(f_r + i_p)}\text{; } f_r=0.1\text{-}0.15; \quad ip=2\%\text{-}2.5\%$$

This form leads to the following:

$$L_3 = \frac{V}{1.8}\sqrt{\frac{B}{127(f_r + i_p)}} \tag{19}$$

If a circular curve is applied in the formation of the change, we obtain the following:

$$L_3 = \sqrt{\frac{BV^2}{18(f_r + i_p)}} = \frac{V}{4.24}\sqrt{\frac{B}{f_r + i_p}} \tag{20}$$

3. Conclusions

The parameters of the previous speed lanes in road junctions (entering lanes) determined as according to the presented methodology are nearest to the realistic conditions and processes, and their application is recommended in motorway junctions both for urban and non-urban roads.

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