Upon an issue of correlation between the running speed of vehicles and traffic capacity of a road section

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Abstract. The paper focuses on current algorithms for calculating the traffic capacity of the road sections, provided in various national standards. These algorithms were jointly considering some common groups of factors, such as factors related to the dynamic performance of vehicles and factors related to geometrical - dimensional configuration of the road. The algorithms have particular forms for continuous traffic flow and for discontinuous traffic. As a first stage, there were considered the algorithms for the continuous flows, for which were studied the points of extreme variance for traffic capacity, depending on the running speed. Maximum traffic capacity analytical form for a road section, in continuous traffic flow variant does not depend explicitly of average speed, but allows the evaluation of certain important factors (length section, acceleration at start-up, braking deceleration of vehicles, driver's perception-reaction time, brake friction coefficient, etc.). Consequently, various ways are identified to improve road traffic capacity. The paper justifies reconsideration of the notion of traffic fluence as defined by various national standards; as it stands, the definition of fluency is artificial in relation to the maximum legal speed on that road section, even though the value of that speed is physically impossible.

1. Introduction.

The most important functional parameter being evaluated in designing any roads is its circulation capacity. The operating unit of an artery is the lane, whose traffic capacity is in fact the maximum flow of vehicles that can be taken by the respective lane in the time unit, which, in the simple version of continuous flows is analytically expressed \([1]\):

\[
N_c = \frac{1000v}{i_{\text{min}}}
\]

\((1)\)

where: \(v \text{ [m/s]}\) – constant speed of the vehicles flow; \(i_{\text{min}} \text{ [m]}\) – minimum sequence space between the flow’s vehicles, and which is calculated based on the required distance for safely stop the vehicle, as follows:

\[
i_{\text{min}} = \frac{v^2}{g \varphi} + v \cdot t_r + S
\]

\((2)\)

with \(g = 9.81 \text{ [m/s}^2]\) – gravitational acceleration; \(\varphi \text{ [-]}\) – brake friction coefficient; \(S \text{ [m]}\) – safety space between vehicles; \(t_r \text{ [s]}\) – perception – reaction time of the vehicles drivers.

This algorithm is applicable to continuous flows of vehicles, or those who travel long distances with absolute priority.
Local restrictions, where the vehicles flow gives priority to other vehicles or pedestrians flows (eg, crosswalks or intersections of the arteries), gives the character of discontinuity for the analyzed flow.

Discontinuous flow traffic capacity \( N_d \) [1] is achieved by improving the continuous flow traffic capacity \( N_C \) by a subunity discontinuity factor \( f_d \) [-]:

\[
N_d = N_C \cdot f_d \tag{3}
\]

\[
f_d = A/v \cdot \left[ \frac{A}{v^2} + \frac{v}{2} \cdot \left( \frac{1}{a} + \frac{1}{d} \right) + T_r \right]^{-1} = 2A \cdot \left[ 2A + v^2 \cdot \left( \frac{1}{a} + \frac{1}{d} \right) + 2 \cdot v \cdot T_r \right]^{-1} \tag{4}
\]

where: \( A \) [m] – the distance between intersections / pedestrian crossings, on the road sections where the traffic capacity is to be determined; \( a \) [m/s²] – average acceleration of vehicles on departure; \( d \) [m/s²] – the absolute value of the average deceleration of the vehicle when stopping; \( T_r \) [s] – the sum of red and yellow times for the traffic light cycle of the intersection where the analyzed vehicle flow accedes. Obviously, at intersections with no traffic lights, \( T_r = 0 \) [s].

2. Analysis of the maximum traffic capacity

The idea of maximum traffic capacity analysis started from a finding of the authors occasioned by the traffic censuses practice as a necessary stage in traffic management projects [2]. Thus, it was observed that for a given section of a road artery, the maximum traffic capacity is recorded at a moderate speed for the vehicles flow, and not at levels around the speed limit for that artery.

In this paper, the authors concerns are limited to the analysis of traffic capacity for continuous flows, and focused on identifying the main influence factors and determining the action of these factors on traffic capacity. In terms of analytical, the most complex influence on the traffic capacity is exerted by the traffic speed, \( v \).

The extreme points for the function \( N_C = N_C(v) \) will be found for those speed values \( v_{ex} \) identified as solutions of the equation \( dN_C/dv = 0 \) [3]. So:

\[
N_C = N_C(v) = 1000 \cdot v \cdot \left( \frac{v^2}{g \cdot \varphi} + v \cdot t_r + S \right)^{-1} \tag{5}
\]

\[
dN_C/dv = 0 \quad \text{is equivalent to:} \quad v^2/(g \cdot \varphi) - S = 0 \quad \text{or} \quad v = \pm \sqrt{S \cdot g \cdot \varphi}
\]

The negative solution \( v = -\sqrt{S \cdot g \cdot \varphi} \) has no physical meaning in our problem so that it will be retained the unique solution:

\[
v_{ex} = \sqrt{S \cdot g \cdot \varphi} \tag{6}
\]

The value for the maximum traffic capacity will be:

\[
N_{C_{max}} = N_C(v_{ex}) = 1000/[t_r + 2\sqrt{S/(g \cdot \varphi)}] \tag{7}
\]

where all the data involved are known.

We notice that the speed \( v_{ex} \) for which is registered the maximum amount of traffic capacity depends (according to the equation (6)) explicitly only on the parameters \( S \) and \( \varphi \) and, paradoxically, not on the \( t_r \), perception – reaction time of the driver. This aspect is also illustrated in the graphical representation in figure 1.

For those parameters that influence the capacity were considered reasonable and achievable domains of variation, respectively \( 0,4[s] \leq t_r \leq 1,0[s] \) and \( 10[km/h] \leq v \leq 50[km/h] \).
Figure 1. Variation of traffic capacity with traffic speed \( v \), for various values of perception – reaction time, \( t_r \).

Usually in the design calculations for the time \( t_r \) values used are between 0,6–0,8[s], specific to subjects of average age and driving in preventive manner [4].

Regarding the traffic speed, it was considered the plausible area in urban environment, upper limited to the amount of legal speed limit. The dependence \( N_C = N_C(v, t_r) \) illustrated in figure 1 considered constant values for \( S=4,5 \) [m] and \( \phi = 0,6[-] \).

In conclusion, the maximum traffic capacity is obtained for a speed \( v_{max}=18,5[\text{km/h}] \) and increases between 363 and 465 [vehicles/hour], when \( t_r \) decreases between 1,0 and 0,4[s].

In a second approach were studied the influence of traffic speed \( v \) and safety space \( S \) on maximum traffic capacity, the results being illustrated in figure 2.

Figure 2. Variation of traffic capacity with traffic speed \( v \) for various values for safety space \( S \)
For the other parameters were considered the constant values $\varphi = 0.6[-]$ and $t_r = 1.0[\text{s}]$. The safety space $\text{"S"}$ varies between 3.0 and 6.0[m], and the speed between 10 and 50[km/h].

The maximum traffic capacity values are obtained at speeds that increase between 15.1 [km/h] and 21.4 [km/h], when the safety space increases between 3 and 6 [m]. On the other hand, the above mentioned increased values for the safety space $\text{"S"}$ lowers the maximum traffic capacity from 411 to 311 [vehicles/hour].

In figure 3 were synthesized the simultaneous influences of traffic speed $\text{"v"}$ and brake friction coefficient $\text{"\varphi"}$, on the traffic capacity of the road artery. For the other parameters constant values were considered, respectively $S = 4.5$ [m] and $t_r = 1.0$ [s]. The brake friction coefficient $\text{"\varphi"}$ varies between limits set by average rolling conditions, relative to the tire and the road [4], ($\varphi = 0.45 \div 0.75[-]$), with the speed values between normal limits ($v=10\div50$ [km/h]).

![Figure 3](image)

**Figure 3.** Variation of traffic capacity with traffic speed $\text{"v"}$ for various values for brake friction coefficient $\text{"\varphi"}$

We notice that the maximum capacity values are achievable for running speeds between 16.0 and 20.7 [km/h], increasing from 331 to 390 [vehicles/hour], when the brake friction coefficient increases between 0.45 and 0.75 [-]

The discontinuity factor $f_d$ can be considered as $\lim_{\lambda \to \infty} f_d = 1$, for the usual values of the parameters $\text{"v"}$, $\text{"m"}$, $\text{"d"}$, $\text{"t"}$ (corresponding to appropriate physical reality), meaning that for longer road sections the discontinuous vehicle flow turns into a continuous flow ($N_C = N_D$), even in urban areas.
3. Conclusions
The traffic capacity influence factors analytically identified are: traffic speed \( v \), safety space \( S \), brake friction coefficient \( \varphi \) and perception - reaction time \( t_r \). The traffic capacity presents a parabolic variation with the running speed \( v \), and registers a maximum value for a speed value that depends explicitly only on safety space \( S \) and brake friction coefficient \( \varphi \). When the influence factors range between usual and plausible limits \( t_r=0.4\div1.0 \,[\text{s}], \ \varphi=0.45\div0.75 \,[-], \ S=3\div6 \,[\text{m}] \), the maximum traffic capacity for one lane ranges between 311 and 465 [vehicles/hour], the speed at which the maximum capacity is recorded varying within tight limits \( 15\div21 \,[\text{km/h}] \). Increased traffic speed over these values lead to important decrease in traffic capacity.

4. References
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