PROPOSAL OF CAPACITY CALCULATION OF FOUR-LEG INTERSECTION WITHOUT "STRAIGHT" TRAFFIC PRIORITY

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Summary: This paper deals with problem of capacity calculation of four-leg intersection after change of traffic priority. This paper was prepared with financial support for project FRVŠ 2206/2011/F1/d "Innovation of Learning of Subjects from the Design of Urban Roads and Intersections".

Key words: Intersection, Capacity, Road Transport.

INTRODUCTION

There is a continual increase in traffic volume on the highways in the Czech Republic. This leads to frequent traffic jams, especially in places where roads intersect – on the intersections. Hence we need to look for new intersections with greater capacity – e.g. roundabouts, intersections with traffic lights etc. In some cases it is sufficient and more cost-effective to implement only minor building modifications or traffic-engineering measures (e.g. change of traffic priority). Capacity calculations of uncontrolled level intersections are described in the TP 188 (1). This standard describes only the intersections with "straight" traffic priority (when Major Street leads straight). For purposes of capacity calculations of intersections without "straight" traffic priority (when Major Street doesn't lead straight) TP 188 can also be used but the formulas should be adjusted.

This paper shows these adjustments for four-leg intersection without "straight" traffic priority.

1. DEGREES OF SUPERIORITY OF TRAFFIC FLOWS

The traffic flows on four-leg intersection in accordance with TP 188 (1) are shown in Fig. 1 (left picture). Flows 2, 3, 8 and 9 (through and right-turning movements from the Major Street) have absolute priority and they are called as the traffic flows of degree 1 (1st degree of superiority of traffic flow).

Flows 1 and 7 (left-turning movements from the Major Street) and Flows 6 and 12 (right-turning movements from the Minor Street) are called as the traffic flows of degree 2 (2nd degree of superiority of traffic flow). They must give priority to traffic flows of degree 1.

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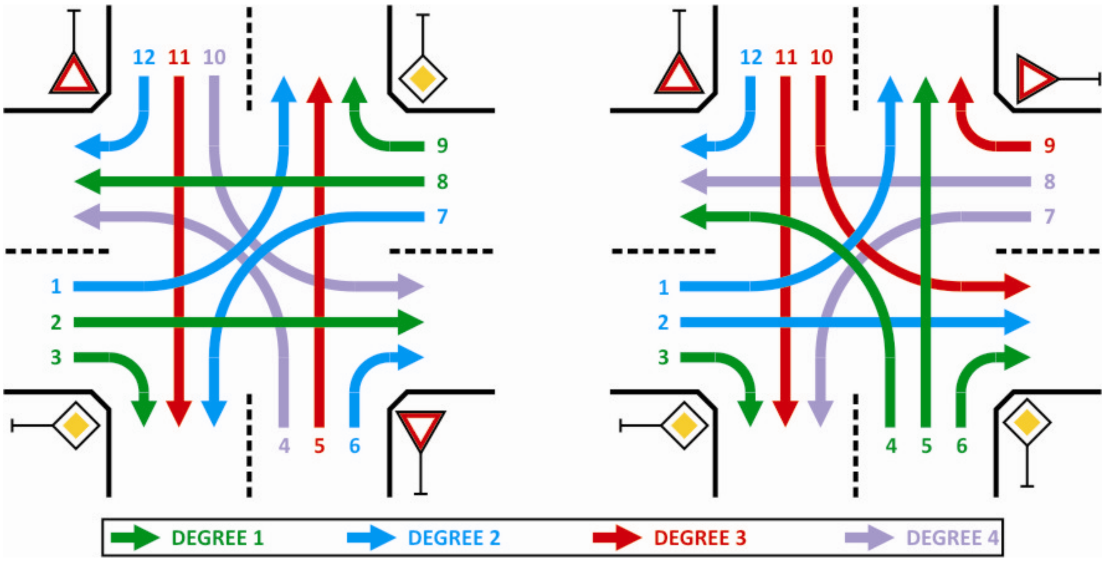
Flows 5 and 11 (through movements from the Minor Street) they are called as the traffic flows of degree 3 (3^{rd} degree of superiority of traffic flow). They must give priority to traffic flows of degrees 1 and 2.

Flows 4 and 10 (left-turning movements from the Minor Street) they are called as the traffic flows of degree 4 (4^{th} degree of superiority of traffic flow). They must give priority to traffic flows of degrees 1,2 and 3.



Source: TP 188 + Author

Fig. 1 – Degrees of superiority of traffic flows

The situation at the intersection without "straight" traffic priority is different – see Fig. 1 (right picture). There are four traffic flows of degree 1 (flows 3, 4, 5 and 6), three traffic flows of degree 2 (flows 1, 2 and 12), three traffic flows of degree 3 (flows 9, 10 and 11) and two traffic flows of degree 4 (flows 7 and 8).

2. DECISIVE FLOW RATES

Decisive flow rates I_H for the intersections with "straight" traffic priority (in accordance with TP 188 (1)) are described as follows:

$$I_{H1} = I_8 + I_9 \tag{1}$$

$$I_{H7} = I_2 + I_3 \tag{2}$$

$$I_{H6} = I_2 + \left(0{,}5.I_3^{*}\right) \tag{3}$$

$$I_{H12} = I_8 + \left(0{,}5.I_9^{*}\right) \tag{4}$$

$$I_{H5} = I_1 + I_2 + \left(0{,}5.I_3^{*}\right) + I_7 + I_8 + I_9 \tag{5}$$

$$I_{H11} = I_1 + I_2 + I_3 + I_7 + I_8 + \left(0{,}5.I_9^{*}\right) \tag{6}$$

$$I_{H4} = I_1 + I_2 + \left(0{,}5.I_3^{*}\right) + I_7 + I_8 + \left(0{,}5.I_9^{*}\right) + I_{11} + I_{12} \tag{7}$$

$$I_{H10} = I_1 + I_2 + \left(0{,}5.I_3^{*}\right) + I_5 + I_6 + I_7 + I_8 + \left(0{,}5.I_9^{*}\right) \tag{8}$$

*) If traffic flow 3 or 9 has auxiliary lane, than I_3 or $I_9 = 0$.

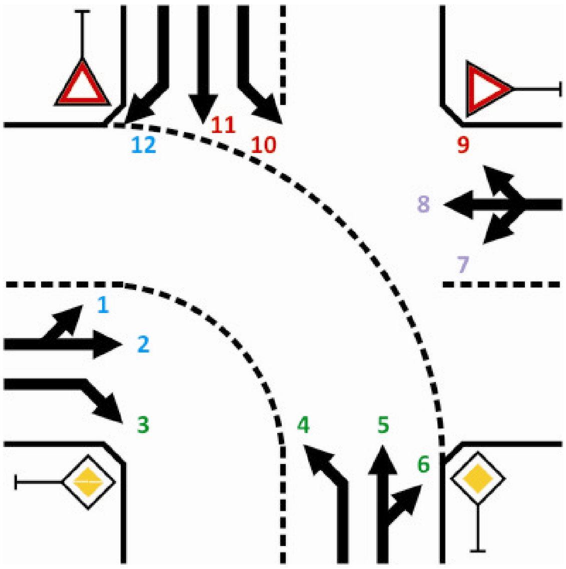


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Fig. 2 – Intersection without "straight" traffic priority (example)

Decisive flow rates for the intersections without "straight" traffic priority (in accordance with intersection in Fig. 2) then can be described as follows (using the philosophy used in formulas (1) – (8) – see above):

- traffic flows of degree 2:

$$I_{H1} = I_4 + I_5 + 0{,}5.I_6 \quad (9)$$

$$I_{H2} = I_4 + I_5 + I_6 \quad (10)$$

$$I_{H12} = I_4 \quad (11)$$

- traffic flows of degree 3:

$$I_{H9} = I_1 + 0{,}5.I_2 + I_5 + 0{,}5.I_6 \quad (12)$$

$$I_{H10} = I_1 + I_2 + I_5 + I_6 \quad (13)$$

$$I_{H11} = I_1 + I_2 + I_3 + I_4 \quad (14)$$

- traffic flows of degree 4:

$$I_{H7} = 0{,}5.I_1 + I_2 + I_3 + I_4 + I_5 + 0{,}5.I_6 + I_{10} + I_{11} \quad (15)$$

$$I_{H8} = I_1 + 0{,}5.I_2 + I_4 + I_5 + 0{,}5.I_6 + I_{10} + I_{11} + I_{12} \quad (16)$$

3. CAPACITY OF TRAFFIC FLOWS

3.1 Basis capacity

Basic capacity G_n of traffic flows of degree 1 is 1800 unit vehicles per hour (u.v./h). Basic capacity of traffic flows of degree 2 (or 3 or 4) is calculated as follows (1):

$$G_n = \frac{3600}{t_{fn}}.e^{-\frac{I_{Hn}}{3600}\left(t_{gn} - \frac{t_{fn}}{2}\right)} \quad (17)$$

where:

n ... number of traffic flow (1, 2, 7, 8, 9, 10, 11, 12),
t_g ... critical gap [s],
t_f ... follow-up time [s].

3.2 Capacity of traffic flows

Capacity C_n of traffic flows of **degree 1 and 2** equals basic capacity of these traffic flows.

Capacity of traffic flows of **degree 3** (using the philosophy according to TP 188) is then as follows (now only for our example of the intersection, which is shown in Fig. 2):

$$C_9 = p_{o,1}.G_9 \tag{18}$$

$$C_{10} = p_{o,1}.p_{o,2}.G_{10} \tag{19}$$

$$C_{11} = p_{o,1}.p_{o,2}.G_{11} \tag{20}$$

where:

$p_{o,n}$ ... probability that no vehicle is queuing at the entry (for the traffic flow of higher degrees of superiority – here degree 2)

$$p_{o,n} = \max\begin{Bmatrix} 1-\dfrac{I_n}{C_n} \\ 0 \end{Bmatrix} \quad \text{(generally [1])} \tag{21}$$

where I_n ... flow rates (u.v./h).

Then:

$$C_9 = \max\begin{Bmatrix} 1-\dfrac{I_1}{C_1} \\ 0 \end{Bmatrix} . G_9 \tag{22}$$

$$C_{10} = \max\begin{Bmatrix} 1-\dfrac{I_1}{C_1} \\ 0 \end{Bmatrix} . \max\begin{Bmatrix} 1-\dfrac{I_2}{C_2} \\ 0 \end{Bmatrix} . G_{10} \tag{23}$$

$$C_{11} = \max\begin{Bmatrix} 1-\dfrac{I_1}{C_1} \\ 0 \end{Bmatrix} . \max\begin{Bmatrix} 1-\dfrac{I_2}{C_2} \\ 0 \end{Bmatrix} . G_{11} \tag{24}$$

Capacity of traffic flows of **degree 4** is dependent on the probability $p_{o,n}$ of the traffic flow of degree 2 (formula (21)) and also on the probability $p_{z,n}$ of the traffic flow of degree 3:

$$p_{z,n} = \frac{1}{1+\dfrac{1-p_x}{p_x}+\dfrac{1-p_{o,n}}{p_{o,n}}} \quad \text{(generally [1])} \tag{25}$$

where $p_x = p_{o,\_}.p_{o,\_}\ldots$ (according to relevant traffic flows) (26)

Recapitulation:

$p_{o,n}$ ... probability that no vehicle is queuing at the entry (for traffic flow of degree 2; see above – formula (21))

$p_{z,n}$ ... probability that no vehicle is queuing at the entry (for traffic flow of degree 3; see above – formula (25))

Capacity of traffic flows of degree 4 (again using the philosophy according to TP 188) is then as follows (<u>and again only for our example of the intersection, which is shown in Fig. 2</u>):

$$C_7 = p_{o,2} \cdot p_{z,10} \cdot p_{z,11} \cdot G_7 \tag{27}$$

where the traffic flow 7 is influenced by flow 2 (degree 2) and by flows 10 and 11 (degree 3), which are influenced by flows 1 and 2 (degree 2)

and where:

$$p_{z,10} = \frac{1}{1 + \frac{1 - p_{o,1} \cdot p_{o,2}}{p_{o,1} \cdot p_{o,2}} + \frac{1 - p_{o,10}}{p_{o,10}}} \tag{28}$$

$$p_{z,11} = \frac{1}{1 + \frac{1 - p_{o,1} \cdot p_{o,2}}{p_{o,1} \cdot p_{o,2}} + \frac{1 - p_{o,11}}{p_{o,11}}} \tag{29}$$

and:

$$C_8 = p_{o,1} \cdot p_{o,12} \cdot p_{z,10} \cdot p_{z,11} \cdot G_8 \tag{30}$$

where the traffic flow 8 is influenced by flows 1 and 12 (degree 2) and by flows 10 and 11 (degree 3), which are influenced by flows 1 and 2 (degree 2), and where $p_{z,10}$ and $p_{z,11}$ see formula (28) and (29).

Then:

$$C_7 = p_{o,2} \cdot \frac{1}{1 + \frac{1 - p_{o,1} \cdot p_{o,2}}{p_{o,1} \cdot p_{o,2}} + \frac{1 - p_{o,10}}{p_{o,10}}} \cdot \frac{1}{1 + \frac{1 - p_{o,1} \cdot p_{o,2}}{p_{o,1} \cdot p_{o,2}} + \frac{1 - p_{o,11}}{p_{o,11}}} \cdot G_7 =$$

$$= \max\begin{Bmatrix} 1 - \frac{I_2}{C_2} \\ 0 \end{Bmatrix} \cdot \frac{1}{1 + \frac{1 - \max\begin{Bmatrix} 1 - \frac{I_1}{C_1} \\ 0 \end{Bmatrix} \cdot \max\begin{Bmatrix} 1 - \frac{I_2}{C_2} \\ 0 \end{Bmatrix}}{\max\begin{Bmatrix} 1 - \frac{I_1}{C_1} \\ 0 \end{Bmatrix} \cdot \max\begin{Bmatrix} 1 - \frac{I_2}{C_2} \\ 0 \end{Bmatrix}} + \frac{1 - \max\begin{Bmatrix} 1 - \frac{I_{10}}{C_{10}} \\ 0 \end{Bmatrix}}{\max\begin{Bmatrix} 1 - \frac{I_{10}}{C_{10}} \\ 0 \end{Bmatrix}}} \cdot$$

$$\cdot \frac{1}{1 + \frac{1 - \max\begin{Bmatrix} 1 - \frac{I_1}{C_1} \\ 0 \end{Bmatrix} \cdot \max\begin{Bmatrix} 1 - \frac{I_2}{C_2} \\ 0 \end{Bmatrix}}{\max\begin{Bmatrix} 1 - \frac{I_1}{C_1} \\ 0 \end{Bmatrix} \cdot \max\begin{Bmatrix} 1 - \frac{I_2}{C_2} \\ 0 \end{Bmatrix}} + \frac{1 - \max\begin{Bmatrix} 1 - \frac{I_{11}}{C_{11}} \\ 0 \end{Bmatrix}}{\max\begin{Bmatrix} 1 - \frac{I_{11}}{C_{11}} \\ 0 \end{Bmatrix}}} \cdot G_7 \tag{31}$$

$$C_8 = p_{o,1} \cdot p_{o,12} \cdot \frac{1}{1+\frac{1-p_{o,1}.p_{o,2}}{p_{o,1}.p_{o,2}}+\frac{1-p_{o,10}}{p_{o,10}}} \cdot \frac{1}{1+\frac{1-p_{o,1}.p_{o,2}}{p_{o,1}.p_{o,2}}+\frac{1-p_{o,11}}{p_{o,11}}} . G_8 =$$

$$= \max\left\{\begin{matrix}1-\frac{I_1}{C_1}\\0\end{matrix}\right\} . \max\left\{\begin{matrix}1-\frac{I_{12}}{C_{12}}\\0\end{matrix}\right\} . \frac{1}{1+\frac{1-\max\left\{\begin{matrix}1-\frac{I_1}{C_1}\\0\end{matrix}\right\}.\max\left\{\begin{matrix}1-\frac{I_2}{C_2}\\0\end{matrix}\right\}}{\max\left\{\begin{matrix}1-\frac{I_1}{C_1}\\0\end{matrix}\right\}.\max\left\{\begin{matrix}1-\frac{I_2}{C_2}\\0\end{matrix}\right\}}+\frac{1-\max\left\{\begin{matrix}1-\frac{I_{10}}{C_{10}}\\0\end{matrix}\right\}}{\max\left\{\begin{matrix}1-\frac{I_{10}}{C_{10}}\\0\end{matrix}\right\}}} .$$

$$. \frac{1}{1+\frac{1-\max\left\{\begin{matrix}1-\frac{I_1}{C_1}\\0\end{matrix}\right\}.\max\left\{\begin{matrix}1-\frac{I_2}{C_2}\\0\end{matrix}\right\}}{\max\left\{\begin{matrix}1-\frac{I_1}{C_1}\\0\end{matrix}\right\}.\max\left\{\begin{matrix}1-\frac{I_2}{C_2}\\0\end{matrix}\right\}}+\frac{1-\max\left\{\begin{matrix}1-\frac{I_{11}}{C_{11}}\\0\end{matrix}\right\}}{\max\left\{\begin{matrix}1-\frac{I_{11}}{C_{11}}\\0\end{matrix}\right\}}} . G_8 \qquad (32)$$

Next calculation (reserve of capacity, average delay and level of service) is identical as the calculation according to TP 188 (1).

4. RESULTS

The presented calculation procedure can be used in capacity calculations of four-leg intersections without "straight" traffic priority (when Major Street doesn't lead straight). The capacity calculations of this type of intersection cannot be counted either by standard procedures according to TP 188 (1) or by special software EDIP-Ka (which is meant only for T-intersections and four-leg intersections).

This paper shows the procedure of capacity calculation for intersection, which has the types of auxiliary traffic lanes according to Fig. 2. It is very important to take into consideration these types, which influence for example decisive flow rates I_H, probability that no vehicle is queuing at the entry etc.

This paper was prepared with financial support for project FRVŠ 2206/2011/F1/d "Innovation of Learning of Subjects from the Design of Urban Roads and Intersections" (2).

REFERENCES

(1) *TP 188 Posuzování kapacity neřízených úrovňových křižovatek.* Liberec: EDIP, 2007. 64 p. ISBN 978-80-902527-6-9.

(2) KŘIVDA, V.; ŠKVAIN, V. *Inovace výuky předmětů z oblasti navrhování městských komunikací a křižovatek.* Project FRVŠ No. 2206/2011/F1/d. Ostrava: VSB – Technical University of Ostrava, Faculty of Civil Engineering, Department of Transport Constructions, 2011.