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Methodology for Analysing Capacity and Level of Service for Roundabouts with one Lane (HCM 2000)

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Abstract

As the motorisation augments in urban areas, different solutions are required, considering the traffic network. In order to adjust the urban arrangement with the need for mobility, complex process of planning and designing is required. City development contains adequate incertitude which causes difficulty during the process of planning and designing. According to this, the process of planning and designing the city infrastructure network are mutually connected and inevitable. Traffic planning is a base of successful functioning in urban areas. With adequate analysis about city development and traffic, the planning process can begin, and be followed by the designing process and building the traffic network. Analysis of capacity and level of service are necessary, in order to obtain the delay of the analysed facilities. These analyses can be empirical and analytical. The empirical model is based on regression analysis, and the analytical model uses the gap – acceptance theory. Empirical models provide better results, but can be used in cases where few roundabouts are congested, to calibrate the model. Othewise, gap – acceptance methods are used to analyse uncongested roundabouts.

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Keywords: roundabout, capacity, level of service, Highway Capacity Manual, delay, gap – acceptance, planning, designing

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1. Introduction

City roads intersect in junctions or intersections. Intersections connect roads on one level, while junctions are used for roads on two or more levels. Roundabouts are intersections where two or more legs cross, by moving around the roundabout island, in opposite direction from the direction of clock arrows.

When two roads of same rang intersect, classical intersection are used. In case roads of different range intersect, roundabouts are more practical. Considering the volume, roundabout is better for similar volumes. In case the volumes are different, which means one of the roads is preferential, classical signalized intersection is better solution. To analyse a roundabout, there must be information for entry flow rate, conflicting flow rate and capacity of entries. Gap – acceptance techniques are applied to estimate the capacity, using parameters for critical gap parameter and follow – up time. In urban areas, pedestrians and bicycles must be considered because they have big influence on the capacity and level of service.

Traffic planning is a base of successful functioning in urban areas. With adequate analysis about city development and traffic, the planning process can begin, and be followed by the designing process and building the traffic network. Analysis of capacity and level of service are necessary, in order to obtain the delay of the analysed facilities [1–8].

2. Methodology

The capacity of roundabout is estimated with gap acceptance techniques, using parameters of critical gap and follow – up time. It is assumed that each leg of the roundabout is analysed independently of the other legs (Fig. 1).

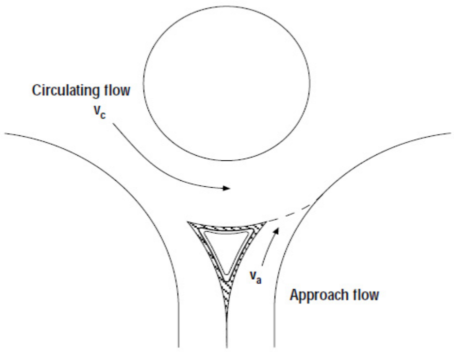

Fig. 1. Analysis on one roundabout leg.

Terms that are used in this analyse are:

- c_a – approach capacity;
- v_a – approach flow rate;
- v_c – circulating flow rate.

The capacity depends on the origin – destination paths at a roundabout, because the increased number of drivers who make a left turn, travel further as a result of a small radius of the roundabout island. This leads to a longer intraplatoon headway, which means lower saturation flow.

2.1. Critical gap and follow – up time

Critical gap (t_c) presents the minimum time interval in the major street stream that allows minor street vehicle to enter the intersection. The minimum gap that a driver uses is defined as critical. Any gap less than the critical would be rejected.

The time between the departure of one vehicle from the minor street and the next one, following the same major – street gap, is defined as follow – up time (t_f). This means that the follow – up time defines the saturation flow rate for the approach.

$$t_{c,x} = t_{c,base} + t_{c,HV}P_{HV} + t_{c,G}G - t_{c,T} - t_{3,LS}, \tag{1}$$

$t_{c,x}$ – critical gap for movement x (s); $t_{c,base}$ – basic critical gap – Table 1 (s); $t_{c,HV}$ – adjustment factor for heavy vehicles (1.0 for two-lane major streets and 2.0 for four-lane major streets) (s); P_{HV} – proportion of heavy vehicles for minor movements; $T_{c,G}$ – adjustment factor for grade (s); G – Percent grade divided by 100; $t_{c,T}$ – adjustment factor for each part of a two-stage gap acceptance process (s), and $t_{3,LS}$ – adjustment factor for intersection geometry (s).

Table 1. Base critical gaps and follow-up times.

Vehicle movements	Base critical gap $t_{c,base}$ (s)		Base follow – up time $t_{f,base}$ (s)
	Two-lane major street	Four-lane major street	
Left turn from major	4.1	4.1	2.2
Right turn from major	6.2	6.9	3.3
Through traffic on minor	6.5	6.5	4.0
Left turn from minor	7.1	7.5	3.5

$$t_{f,c} = t_{f,base} + t_{f,HV}P_{HV}, \tag{2}$$

$t_{f,c}$ – follow-up time for minor movement x (s); $t_{f,base}$ – basic follow-up time, Table 1 (s); $t_{f,HV}$ – adjustment factor for heavy vehicles (0.9 for two-lane major streets and 1.0 for four-lane major streets); P_{HV} – proportion of heavy vehicles for minor movements.

2.2. Control delay

The delay depends on many factors, such as control, geometrics, traffic and incidents. Total delay is defined as the difference between the actual travel time and the reference travel time in base conditions, in absence of incident, control, traffic or geometry delay.

Control delay includes initial deceleration delay, queue move-up time, stopped delay and final acceleration delay. The total time between the time when the vehicle stops at the end of the queue and the time when the vehicle departs from the stop line is called total delay.

Average control delay for any minor movement is a function of the capacity of the approach and the degree of saturation. In the process of estimation the control delay, the analytical model assumes that the demand is less than capacity for the analysed period. The control delay can be calculated with the following equation:

$$d = \frac{3600}{cm,x} + 900T\left[\frac{vx}{cm,x} - 1 + \sqrt{\left(\frac{vx}{cm,x} - 1\right)^2 + \frac{\left(\frac{3600}{cm,x}\right)\left(\frac{vx}{cm,x}\right)}{450T}}\right] + 5\,, \tag{3}$$

d – control delay (s/veh); v_x – flow rate for movement x (veh/h); $c_{m,x}$ – capacity of movement x (veh/h); T – analysis time period (h) (T = 0.25 for a 15-min period).

The constant 5 is added to the equation to account the deceleration of vehicles from free-flow speed to the speed in the queue and the acceleration from the stop line to the free-flow speed.

2.3. Level of service

The level of service at a roundabout is determined by calculating or measuring the control delay of each movement on the minor street. As a result of different conditions and driver's perception, level of service is different at the signalized and unsignalized intersections. The level of service, depending on the control delay is given in Table 2.

Table 2. Level of service for roundabout.

Level of service	Control delay (s/veh)
A	0–10
B	>10–15
C	>15–25
D	>25–35
E	>35–50
F	>50

2.4. Capacity

The capacity of a roundabout approach is estimated with Equation 4:

$$c_a = \frac{vce^{-vctc/3600}}{1-e^{-vctf/3600}}, \quad (4)$$

c_a – approach capacity (veh/h); v_c – conflicting circulating traffic (veh/h); t_c – critical gap (s); t_f – follow-up time (s).

Some studies indicate that a range of values for critical gap and follow-up time can provide a reasonable estimate of the approach capacity. The recommended ranges are given in Table 3.

Table 3. Values of critical gap and follow-up time for roundabouts.

	Critical gap (s)	Follow-up time(s)
Upper bound	4.1	2.6
Lower bound	4.6	3.1

For these values of critical gap and follow-up time, the relationship between the approach capacity and circulating flow is given in Fig. 2.

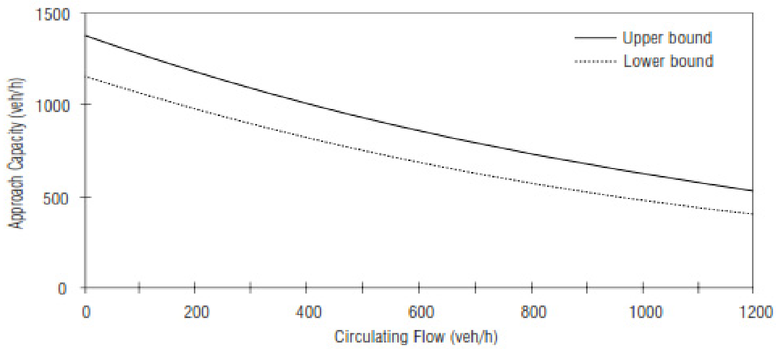

Fig. 2. Approach capacity for roundabout.

To calculate the conflicting flows, 15-min volumes are estimated. In order to calculate the conflicting flow, the turning movements that affect this flow must be converted in circulating flows. For example, circulating flow for movements 7, 8 and 9 are movements 1, 2 and 10 ($v_c = v_1 + v_2 + v_{10}$) (Fig. 3).

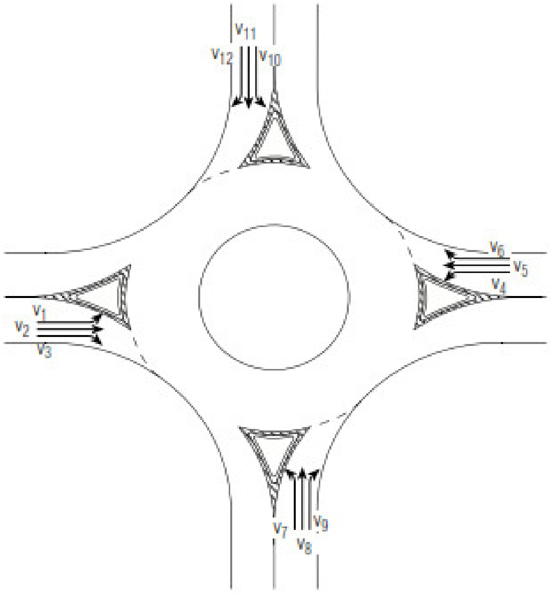

Fig. 3. Flow stream definitions.

This method is only used for roundabouts with one lane. Multiple-lane roundabouts have different conditions, therefore they demand more complexes analysis. Anyway, the experience shows that the capacity does not increase proportionally with the number of lanes. In other words, the effect is less than the effect of full additional lane.

3. Conclusions

In urban areas roundabouts are used more often, usually when two roads of different range intersect, and the volume is not enough for signalized intersection. Pedestrians and bicycles must be considered as well, such as the vehicles from public city transport. The problem with pedestrians and bicycles must be solved in the intersection area (adequate passages must be defined).

First step in analyzing is defining the volume, in order to determine the major and minor stream. Once we have this information, control delay can be calculated in order to obtain the level of service. In case the level of service is not satisfied, there must be considered other solutions, such as multiple-lane roundabout, signalized intersection or junction. In case the capacity and level of service are satisfied, analysis for the next period are required. If the capacity and level of service are not provided in the moment or in the next period, some changes should be proposed, such as:

- Different solution for the intersection,
- Transferring the vehicles to the existing traffic network,
- Decrease the influence of the public city transportation with an exclusive lane,
- Only using the city center network for pedestrians and bicycles, vehicles should use the rest of the traffic network.

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