Methodology for analysing capacity and level of service for signalized intersections (HCM 2000)

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Abstract. The augmentation of motorization level leads us to the need for mobility and demands better infrastructure, in urban and suburban areas. The complexity of this problem is esspecialy notable in urban areas where the need for mobility must be considered, as well as the integration of infrastructure network in the urban plan of the city. Besides the space delimitations, functional characteristics and space demands connected with different transportation in cities.
This methodology analyses the needs of the urban traffic network in highly populated areas, where space limitation and movements in peak hours must be considered. That is why the analysis of capacity and level of service is key part of the urban traffic planning.
Highway Capacity Manual gives the opportunity to analyse the capacity and level of service of the roads in urban or rural areas, by defining the delay of the analysed facilities. To obtain these information, we must have data for geometric, traffic and signalization parameters, when the intersection is signalized.

1 Introduction

In urban areas, the flow is analysed as interrupted, because of the signalisation, pedestrians or bicycles. With these interruptions, the moving time for traffic participants increases. Bigger moving time leads to bigger delay, which is the main indicator for capacity and level of service (LOS).

If the delay has lower value, the LOS is better, and if the delay has higher value the LOS decreases.

In order to obtain these information, there must be information for geometric, traffic and signalization parameters.

First step in determining the capacity and LOS is Lane Grouping. This means grouping the lanes by the movements (left, right turns and through movements).

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2 Methodology

Each lane group is analysed separately. There are two approaches for this capacity analysis. The first one allows quick estimation for one cycle length and green times, in order to constitute a signal timing plan. The second estimation procedure is more complicated and provides the basis for the design of signal plan that equalize the degree of saturation on the critical approach for each phase.

The first approach allows quick analyses with minimal input field data, which makes it very simple to use, considering the default values for the required traffic and control parameters.

This methodology includes few steps:

- Lane grouping and Demand flow rate
- Saturation flow rate
- Capacity and v/c
- Performance measures

Capacity is defined by the saturation flow and saturation flow rate, and the LOS is defined by control delay per vehicle. Signalized intersection methodology is presented in figure 1.

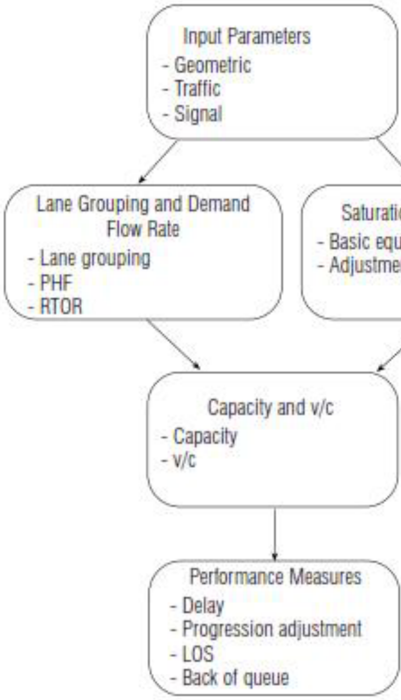

Fig. 1. Signalized intersection methodology.

2.1 Input parameters

In order to conduct an analysis for signalized intersection we must provide some input parameters, such as:

a) Geometric conditions:

- Area type

- Number of lanes N,
- Average lane width W (m),
- Grade G (%),
- Existence of exclusive LT or RT lanes,
- Length of storage bay LT or RT lane, L_s (m),
- Parking

b) Traffic conditions

- Demand volume by movement V (veh/h),
- Base saturation flow rate s_0 (pc/h/ln),
- Peak-hour factor PHF,
- Percent heavy vehicles, HV (%),
- Approach pedestrian flow rate v_{ped} (p/h),
- Local buses stopping at intersection N_a (buses/h),
- Parking activity N_m (manoeuvres/h),
- Arrival type AT,
- Portion of vehicles arriving on green P,
- Approach speed S_A (km/h)

c) Signalization conditions

- Cycle length C (s),
- Green time G (s),
- Yellow – plus – all – red change – and – clearance interval (intergreen) Y (s),
- Actuated or pretimed operation,
- Pedestrian push button,
- Minimum pedestrian green G_p (s),
- Phase plan,
- Analysis period T (h)

2.2 Lane grouping

First step in this analysis, after providing input data, is lane grouping, for each approach separately. Lane grouping is very simple procedure, depending from geometric conditions and traffic movements distribution. The lane group describes the manoeuvres in the intersection area:

- Lanes for left turns should be considered separately, unless there is lane for left – through shared lane. In this case, portion of left turns should be computed.
- When there are exclusive left and right – turn lanes, the other lanes go in one lane group.
- If the lane is used for both left – turning and through vehicles, the portion of left turns will determine whether the lane will be considered as exclusive left lane.

2.3 Determining flow rate

Traffic demand is determined by average flow in analysed period (usually 15 minutes). Flow rate during peak 15 minutes period is computed with following equation, using the hourly volume (veh/h) and peak – hour factor.

$$v_p = \frac{V}{PHF} \qquad (1)$$

if right turn is allowed on red light, this volume should be corrected by the traffic volume of right turns on red light.

2.4 Determining saturation flow rate

Saturation flow rate should be determined (computed) for each lane group, and it is considered to be the flow in veh/h in a lane group, assuming the green phase is displayed 100% of the time.

$$s = s_0 \, N \, f_w \, f_{tv} \, f_i \, f_p \, f_{bb} \, f_a \, f_{LU} \, f_{LS} f_{RS} f_{Lpb} \, f_{Rpb} \tag{2}$$

Besides the base saturation flow rate per lane (s_0) and the number of lanes (N), there are included some adjustment factors for:

- Lane width f_w,
- Heavy vehicles in traffic stream f_{HV},
- Approach grade f_g,
- Existence of a parking lane and parking activity f_p,
- Blocking effect of local buses in intersection area f_{bb},
- Area type f_a,
- Lane utilization f_{LU},
- Left turns in lane group f_{LT},
- Right turns in lane group f_{RT},
- Pedestrian and bicycle factor for left and right – turn movements f_{Lbp} and f_{Rbp}.

2.5 Capacity and v/c ratio

a) *Capacity*

Capacity of signalized intersection depends on saturation flow and saturation flow rate. The capacity, for each lane group, can be calculated by the following equation:

$$c_i = s_i \frac{g_i}{C} \tag{3}$$

Where:

s_i – saturation flow rate for lane group i,

g_i/C – effective green ratio for lane group i.

b) *v/c Ratio*

The volume to capacity ratio is presented by the symbol X and is referred to as a degree of saturation.

$$X_i = \left(\frac{V}{C}\right)_i = \frac{Vi}{Si\left(\frac{gi}{C}\right)} = \frac{ViC}{Sigi} \tag{4}$$

In the previous two equations, few inputs are inevitable:

v_i – demand flow rate for lane group,

s_i – saturation flow rate for lane group,

g_i – effective green time for lane group,

C – cycle length.

If the value of X = 1, the flow rate equals capacity. Demand excesses capacity if the value of X is above 1.

c) *Critical lane groups*

When analysing an intersection, it is very important to determine the lane group with highest v/s ratio. This is the lane group that demands longer green light. This means, each phase will have one critical lane group. The critical Xc is calculated with this equation:

$$X_c = \sum\left(\frac{v}{C}\right)_{ci}\left(\frac{C}{C-L}\right) \quad (5)$$

In this equation L represents the total lost time per cycle.

2.6 Determining delay

Values given by the calculated delay represent the average control delay of all vehicles that arrive in the analysed period. The average control delay per vehicle is calculated as:

$$d = d_1(PF) + d_2 + d_3 \quad (6)$$

Where:
d_1 – uniform control delay assuming uniform arrivals (s/veh),
PF – uniform delay progression adjustment factor,
d_2 – incremental delay for random arrivals and oversaturation queues, adjusted for duration of analysis period and type of signal control. This delay assumes that there is no initial queue for lane group at start of analyzed period
d_3 – initial queue delay for all vehicles in analyzed period. This delay appears due to initial queue at start of analyzed period.

2.7 Determining level of service (LOS)

Level of service of an intersection is connected to the average control delay per vehicle. By the value of the delay, we can determine the LOS, according to the following table:

Table 1. LOS for signalized intersection.

Level of service	Control of delays of the vehicles (s/veh)
A	≤ 10
B	> 10-20
C	> 20-35
D	> 35-55
E	>55-80
F	>80

With this method we provide two key outputs:

- v/c ratio for each lane group and for every critical lane group at the intersection

- Average control delay for each lane group, and each approach as well as the intersection as a whole, with appropriate LOS.

Values of v/c ratio higher than 1.0 indicate to actual or potential breakdown. In this case multiple period analyses are recommended. The v/c ratio is bigger then 1.0 usualy as result of inadequate capacity because of signal and geometric characteristics.

In some cases, v/c could be less than 1.0 for the intersection, but v/c for some lane groups can be higher than 1.0. This means that the green light is not appropriately apportioned and the existing phasing should be attempted.

There might be cases where v/c is less than 1.0, but the delay is high because of inappropriately long cycle length, poor progression or both.

When v/c is around 1.0 or exceeds this value, the delay may stay in acceptable limits if the time frame where v/c has high value is short.

3 Conclusions

The planning process is inevitable in city development, and it is connected with the designing process. Traffic volume and geometry are very important in order to achieve the needed capacity and level of service of every street or intersection as a whole. In future, with industry and technology development, the planning process will become more complexed. Therefore, the problem with capacity and level of service should be solved, first in the area of intersection, and then at the approaches. If the offered solution for the intersection does not accomplish the needs, another intersection design should be analyzed.

If none of the solutions resolves the problem with capacity and level of service, some changes in the traffic organization should be proposed, such as:

- To transfer some of the vehicles to the existing traffic net,
- Vehicles of public city transportation should have exclusive lane, which would decrease their influence to the other vehicles,
- The city center may be closed for vehicles, only pedestrians and bicycles should use these streets.

Every important intersection in the city should be analyzed, in order to determine the capacity and level of service.

References

1. R. Bankovich, *Planning of public urban passenger transport, Construction book* (Belgrade, 1984)
2. M. Bublin, *Planning movement and its proximity to the main roads* (Univerzitetsko graduation from the Construction faculty in Sarajevo, Sarajevo, 2007)
3. *Board of international research, Standards on geometric features and traffic intersections in urban road* (Rome)
4. C.R.O.W., Recommendations for traffic provisions in built – up areas, C.R.O.W., (The Netherlands, 1998)
5. R. Doncheva, *Urban sobral* (Faculty of civil engineering, Skopje, 2013)
6. M. Maletin, *City roads* (Faculty of civil engineering, Belgrade, 1996)
7. M. Maletin, *Planning and design due to the proximity to the main roads in cities* (Faculty of civil engineering, Belgrade, 2005)
8. M. Maletin, *Planning, movement and space* (Faculty of civil engineering, Belgrade, 2004)
9. NSRA, *Guidelines for the geometric design of urban roads – rigu73* (National Swedish Road Administration, Stockholm, 1973)

10. *Transportation research board, Highway capacity manual 2000* (National Research Council 2000)
11. *Transportation Research Board, Highway capacity manual 2010* (National Research Council, 2010)