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THE IMPACT OF DIFFERENT SATURATION HEADWAY VALUES ON INTERSECTION CAPACITY

Dražen Cvitanić, Biljana Maljković
University of Split, Faculty of Civil Engineering, Architecture and Geodesy, Croatia

Abstract

Elements of the city road network that determine its capacity are signalized intersections. Their capacity depends of many factors: traffic volume and distribution, traffic flow structure, signal timing, and number of bicyclists and pedestrians. However, the starting parameter for calculation of intersection capacity is saturation headway. This research explores the influence of weather conditions and purpose of trip on saturation headway. Saturation headways were determined on few intersections in the morning peak hour of working and weekend day, in good and bad weather conditions. The impact of different trip purposes and different weather conditions on intersection capacity is analysed, as well as the influence of using mean and median values of saturation headway when calculating the intersection capacity.

Keywords:

1 Introduction

Signalized intersections are elements of the city road network that determine its capacity due to recurring interruptions of traffic, numerous vehicle and pedestrian conflicts as well as limited number of lanes. Therefore, it is very important to accurately estimate their capacity. Factors affecting the capacity of signalized intersections are: traffic volume and distribution, traffic flow structure, signal timing, and number of bicyclists and pedestrians. However, the starting parameter for calculation of intersection capacity is saturation headway, which is not a constant value [1-3]. This research deals with dependence of saturation headway on weather condition and purpose of trip. Saturation headways were determined on few intersections in the morning peak hour of working and weekend day, in good and bad weather conditions (light rain). The influence of different trip purposes and different weather conditions on intersection capacity was analysed, in terms of different saturation headways measured. The impact of using the mean and median values of saturation headways when calculating the intersection capacity and delay was also analysed.

2 Saturation headway, start-up lost time and time-in-queue delay

Headways of vehicles that were in the queue from the beginning of the green phase to the appearance of the first non-passenger vehicle have been recorded at each lane. This provided the data needed to calculate the saturation headway and start-up-lost time. In addition, time-in-queue delay for each vehicle (the total time from a vehicle joined the queue to its discharge across the stop lane) has been recorded. The saturation headway h_s is the average value of the measured headways from the fifth to the last vehicle in the queue before the start of the green phase or until the occurrence of a vehicle that is not passenger (truck, bus, ...) [2, 3].

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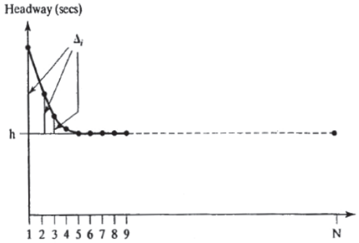


Figure 1 Flow from the queue at signalized intersection [4]

Figure 1 shows that first few vehicles (4) have greater headways because they have to react and accelerate. The additional time above and beyond headway h is defined as start-up lost time:

$$l_1 = \sum_i \Delta_i \tag{1}$$

l_1 – start-up lost time (sec/phase)
Δ_i – incremental headway (above ‘h’ seconds) for vehicle i

Delay is the most commonly used measure for describing the operation of a signalized intersections. Delay can be determined in many ways such as stopped delay, control delay, time-in-queue delay etc. Time-in-queue delay is the time from the vehicle joining an intersection queue to its discharge across the intersection on departure. Control delay is the delay caused by a control device. It is approximately equal to time-in-queue delay plus the acceleration-deceleration delay component.

Since control delay is difficult to measure in the field, the values of time-in-queue delays were quantified in this paper. Control delay was obtained by adding the time required to decelerate from the desired speed to 0 and the acceleration time. The deceleration and acceleration times were obtained using typical rates (2.5 m/sec^2) at intersections [4-6]. The average time lost for acceleration/deceleration was obtained by dividing the sum of lost times (of vehicles that came on red or came at the end of the green light but did not pass the intersection) with the total number of vehicles.

3 Field Survey

3.1 Locations and configurations of the analysed intersections

In order to examine the intersection functioning in different prevailing conditions (structure of traffic flow and driver behaviour), two intersections were analysed, one in Split (Croatia), and the second one in Prague (Czech Republic).

On both intersections, traffic data were collected with video camera in the morning peak hour. In order to analyse different driver’s behaviour for different weather conditions and purpose of trip, recording was performed few times:

1. working day – good weather - dry carriageway
2. working day – bad weather - wet carriageway (light rain)
3. Sunday – good weather - dry carriageway
4. Sunday – bad weather - wet carriageway (light rain)

In morning peak hour on working days, most of the trips were working trips, while in the morning peak hour on Sundays, minor number of trips were working trips.

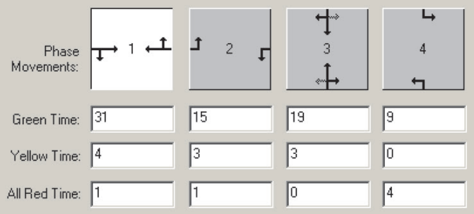
The measurements of saturation headway were carried out in the time period of 7:30 to 8:00 when all manoeuvres on approaches were operated at the capacity limit (occasionally, the queue remains at the end of the green but at the end of the analysed time interval queues were cleared). In this interval, signal cycles were recorded with a video camera and processed by Android application (Headway) developed by programming language Sketchware [7]. Using this application, headway and start-up lost time have been determined. Android application Delay Study (Aspen Technic) [8] was used to measure time-in-queue delay. Of the measured values, the average value of each parameter was obtained. Measurements were made for main movements, where the vehicles pass intersection without interaction with other turning vehicles.

3.1.1 The intersection in Split, Croatia

The first observed intersection is located in Split, at the crossroads of Bruna Bušića and Poljička cesta street (Figure 2). Poljička cesta is long main city road that extends from the entrance of the city to its centre and, therefore, has one of the most heavily traffic volume.

Figure 2 Observed intersection in Split

Direction Q1 is the northern approach and consists of 3 traffic lanes (short left lane and 2 full lanes). Direction Q2 is the eastern approach which consists of 4 traffic lanes (two for through movements, one shared lane for through and right turns, and one exclusive short left lane). Q3 is the southern approach and consists of 3 traffic lanes (one short left lane, one for through and one shared lane for through and right). The west approach Q4 has the same geometry as the Q3. The intersection is signalized in four phases. The approaches Q1 and Q3 have the same phase in which the compound phase of the left turn appears. The approaches Q2 and Q4 have the same phase duration, but there is a completely-protected phase for left turns. The cycle duration is 90 seconds, and the duration of each phase is shown in Figure 3.



Phase Movements:	1	2	3	4
Green Time:	31	15	19	9
Yellow Time:	4	3	3	0
All Red Time:	1	1	0	4

Figure 3 Phases duration

Traffic volume

Traffic data were collected with video camera in the morning peak hour on eastern approach through lane marked on Figure 2. Recorded number of vehicles in morning peak hour for different days and weather conditions is shown in Table 1, where PC denotes passenger cars, BUS is for buses and HV is for heavy vehicles.

Table 1 Table 1. Traffic volume for various conditions (the intersection in Split)

	PC	BUS	HV	TOTAL
Working day – dry carriageway	473	15	27	515
Working day – wet carriageway	467	19	22	508
Sunday – dry carriageway	297	14	16	327
Sunday – wet carriageway	262	13	11	286

3.1.2 The intersection in Prague

Location of second analysed intersection of Svatovske and Milade Horakove streets is in Prague, Czech Republic (Figure 4). It is located near the biggest castle in the world (Prague castle) which is the destination of numerous tourists, so this intersection has high traffic flow intensity.

Figure 4 Observed intersection in Prague

Direction Q1 is the northern approach which consists of 3 traffic lanes (two full left lanes and one right turn lane). The west approach Q2 consists of 3 traffic lanes (2 through lanes and one right turn lane). Direction Q3 is the southern approach which consists of 3 traffic lanes (2 left turn lanes and one right turn lane). This approach is one-way street, that is, there is no exiting traffic. The east approach Q4 consists of 3 traffic lanes (2 through lanes and one left turn lane).

This is signalized intersection with four phases and fully protected left turns from the approaches Q1, Q3 and Q4, while left turn from the approach Q2 is prohibited.

Recorded number of vehicles in morning peak hours is shown in Table 2.

Table 2 Traffic volume for various conditions (the intersection in Prague)

	PC	BUS	HV	TOTAL
Working day – dry carriageway	568	6	33	607
Working day – wet carriageway	440	6	35	481
Sunday – dry carriageway	507	-	10	517
Sunday – wet carriageway	426	3	7	436

4 The impact of applied values of saturation headway on capacity and delay

Tables 3. and 4. show average measured values (sec) of saturation headway (h_s) and average control delay (CD), for analysed intersections in Split and Prague.

Table 3 The values of h_s and CD for the intersection in Split

	Working day – dry carriageway		**Working day – wet carriageway**		**Sunday - dry carriageway**		**Sunday - wet carriageway**	
	h_s	**CD**	**h_s**	**CD**	**h_s**	**CD**	**h_s**	**CD**
Average	1.83	45.34	2.11	48.04	1.86	21.25	2.11	20.29
Median	1.74	n/a	2	n/a	1.77	n/a	2.01	n/a

Table 4 The values of h_s and CD for the intersection in Prague

	Working day – dry carriageway		**Working day – wet carriageway**		**Sunday - dry carriageway**		**Sunday - wet carriageway**	
	h_s	**CD**	**h_s**	**CD**	**h_s**	**CD**	**h_s**	**CD**
Average	1.72	76.2	1.97	77.41	1.84	63.39	2.06	68.77

From tables 3. and 4. it can be seen that saturation headway is higher in wet than in dry carriageway conditions for working and non-working day, in Split as well as in Prague. Saturation headway on working day, for wet carriageway in Split, is 15.3 % higher than in dry conditions (2.11/1.83), while in Prague, it is 14.5 % higher (1.97/1.72), that is, almost the same value. So it can be concluded that drivers react similarly in same prevailing conditions. Saturation flow rate of through lane in vehicles per hour, when the signal continuously show green light, is defined as s = 3600/h. It means that the capacity of intersection through lane in Split and Prague for dry carriageway is 15 % higher than for wet carriageway.

Saturation headway on Sunday for wet carriageway in Split is 13.4 % higher than in dry conditions (2.11/1.86), while in Prague, it is 12 % higher (2.06/1.84), slightly less than in Split. It means that the capacity is 12-13 % higher in dry conditions.

Saturation headway is 1.6 % higher on Sunday than on working day in Split for dry carriageway, while in Prague is 7 % higher. It can be explained by fact that most of drivers do not go to work on Sunday so they are more relaxed. In addition, traffic volume has less intensity, so vehicle queue and delay are smaller and drivers accept higher values.

The differences are smaller for wet carriageway, in Split there is no difference in saturation headway on Sunday and working day, while in Prague the difference is 4 % what is significantly less than for dry carriageway. It can be explained by the fact that saturation headway on Sunday is large enough because drivers are relaxed so the wet carriageway has a little impact on further increase of headway. Average (mean) value of saturation headway for analysed subsets of data is about 5 % higher than median value. In Table 5 is presented descriptive statistics of data on working day on dry carriageway.

Table 5 Descriptive statistics for a sample on working day on dry carriageway

Average	Median	Stand. error	Skewness	Kurtosis
1,84	1,74	0,06	0,68	0,58

The average value for all data subsets is greater than the median while the skewness of headways is positive which is consistent with [1]. It indicates that the distribution of queue discharge headway is likely unsymmetrical so the lognormal distribution should better fit data than normal [1].

The fact that average value of saturation headway h_s is greater than the median value means that more than 50 % drivers will use smaller headway. Therefore, traditional saturation flow rate estimation method would underestimate capacity, i.e. overestimate delay. Hence, it is reasonable to use the median value [1] to calculate the saturation flow rate.

In order to show consequences of using various values of saturation headway, ~~is~~ the analysis of delay for intersection in Split using software SIDRA [9] is conducted in this paper.

The data for working day on dry carriageway were used. Calculations were made for the same values of volume, but for the measured average and median values presented in table 5.

Measured delay for analysed conditions was 45.34 sec, while resulting delays are shown in Figure 5.

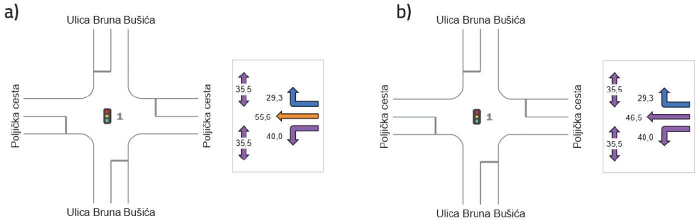


Figure 5 Resulting delays for the intersection in Split

It can be seen that the use of average value of saturation headway results in higher delay than measured (22 %), while using median value results in much better estimation (difference 2.6 %). Similar results were obtained for other conditions (wet carriageway, Sunday).

Considering that this research was conducted for just few hours on 2 intersections, general conclusions cannot be obtained. But, results indicate that there is a need for further research of using appropriate values of saturation headway when calculating capacity and delay in different prevailing conditions. Especially, it is important for different carriageway conditions.

5 Conclusions

This research points to the need for using appropriate values of saturation headway when calculating the intersection capacity and delay. Saturation headway is not a constant value; it depends about driver's characteristics, vehicle fleet, purpose of trip and weather condition, what is shown here.

For wet conditions, saturation headway is up to 15 % higher than for dry conditions on working day (up to 13 % on Sunday), both in Split and Prague. It means that the capacity is about 15(13) % smaller and resulting delay increases exponentially with small decrease of capacity for near saturated conditions.

On the other hand, either mean or median value of headway can be used, for every prevailing condition. Using mean value results with underestimation of capacity i.e. overestimation of delay because mean value of saturation headway is greater than the median value what means that more than 50 % drivers will use smaller headway. Hence, it is reasonable to use the median value [1] to calculate the saturation flow rate.

This research does not give general answers, just indicates a need for further research in this area and opens some questions. The main question is: Which saturation headway value is relevant, median or mean value; that for dry (traditional approach) or wet condition?

So choosing the appropriate value of saturation headway has a significant impact on traffic planning because the small error in capacity estimation results with significantly wrong estimation of control delay, i.e. level of service for near saturated conditions.

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