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28–30 April 2014, Split, Croatia

## Road and Rail Infrastructure III

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## THE USE OF DIFFERENT METHODOLOGIES FOR SATURATION HEADWAYS AND SATURATION FLOW RATES AT SIGNALIZED INTERSECTIONS

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### Abstract

Capacity of signalized intersections relies on two basic parameters; allocated green time and saturation flow rate. Green time proportion depends on traffic demand, lane and phase configurations. Saturation flow rate is directly related to the roadway's environmental features and user's behavioural characteristics which significantly differ between locations. Although Highway Capacity Manual provides general guide for the estimation of saturation flow rate, its recommendations regarding particular values of design parameters, such as base saturation flow and capacity adjustment factors may not be universally applicable. On the other hand, there are a large number of methodologies for the field measurement of saturation headways. It is very important to conclude if the results of these methods are significantly different compared to the nature of the formatted queue. The present study was conducted to determine saturation flow rate for through traffic at a signalized junction in Thessaloniki. The analyses were based on two methodologies for the field measurements. Subsequently, the results of these methodologies compared to each other and to the estimated value of the saturation flow rate provided by the HCM with the use of suggested default values. The research's outputs are very important to draw conclusions for the adequate field methodology, depending on traffic conditions. Furthermore, it will reveal the differences between measured values of saturation flow rate and estimated values though the HCM. The outputs can be used in order to formulate a guide for the use of typical saturation flow rate values and therefore, capacity typical values applied to Greek urban traffic.

*Keywords: saturation flow rate, capacity, signalized junctions, field measurements, Highway Capacity Manual*

### 1 Introduction

The design and the operation of signalized junctions are based on their capacity, which mainly relies on the saturation flow rate in ideal conditions and a number of adjustment factors to describe prevailing geometric and traffic conditions [1]. The Highway Capacity Manual [2], Canadian Capacity Guide [3], and the Australian Road Research Board [4] provide guidelines for estimating the capacity of a signalized intersection. Although all the above manuals specify values for adjustment factors, researchers have observed significant fluctuations between these saturation flow rates and the values that derived from field measurements, because of the variations in driver's behavioural and in the roadway characteristics [1], [5]. Therefore, field measurements are thought to be the most representative method for calculating saturation flow. A great number of methodologies have been developed to measure saturation flow [6], [7], [8], [9] with headways method being the most commonly used. Saturation headways are typically estimated from the elapsed time between the 4<sup>th</sup> and the 10<sup>th</sup>

to 12<sup>th</sup> vehicles in a queue, under the assumptions (1) that there is not significant differences between short and long queues and (2) that the average headway from the first 4 to 12 vehicles is representative for long queues [10].

This study is based on measurements at a through-movement lane in a main arterial street in Thessaloniki. For the field measurements of saturation headways two methods were used. The first method (M1) includes headways between the 4<sup>th</sup> and the 12<sup>th</sup> vehicle in the standing queue, while the second one (M2) entails measurements of all the vehicles in the standing queue. M2 is the method suggested by the HCM and gives a more extensive picture of the queue discharge process [2].

The results of the two methods are being analysed to conclude if the headways derived from them are significantly different and if there is a specific method that should be used depending on the size of the queue. Subsequently, the current research is directed to the estimation of the saturation flow rate through the use of HCM's estimation method. This comparison leads to important outputs on whether the use of values suggested by HCM lead to realistic solutions when intersection operations are examined.

## 2 Literature review

According to Greenshields and his partners [7] the average saturation headway of all the through-moving vehicles after the 5<sup>th</sup> in the queue is 2,1 sec. Later on, in 1956, Bartle and his partners [11], following a similar process applied in the whole access, found that the average headway varied between 0,93 sec and 1,63 sec, with significant differences between different accesses. In 1970, Assmus [12] determined the average headway as the time between the 3<sup>rd</sup> and the last vehicle in the queue and in 1971, Carstens [13], proved that the 1<sup>st</sup> vehicles enters the junction 2,6 sec after the green time starts, the 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> vehicles have an average headway of 2,5 sec, 2,5 sec and 2,3 sec and all the following vehicles 2,3 sec. In 1976, King and Wilkinson [14] proved a decrease in the headways as the vehicle's place in queue increased and that the headway was stabilized from the 5<sup>th</sup> vehicle at 2,2 sec.

Later on, Branston and Van Zuylen [9] through linear regression resulted in the value of 1.750 pc/h/ln. In 1978, Kunzman [15], using almost the same methodology with Carstens, found out that in short queues saturation flow rate was 1.494 pc/h/through lane and in taller ones 1.726 pc/h/through lane. According to HCM 2000 and 2010 [2], the starting point for estimating saturation headway is the 5th vehicle in a standing queue. The headway is estimated by averaging the headways from the fifth to the last vehicle. Teplý and Jones [16] indicated that the American, Canadian and Australian manuals have similar definition and measurement methods for saturation headway.

This is the crucial point in time when research is directed to a different approach. Typically, the discharge headway is considered to be stabilized after the 4<sup>th</sup> vehicle in the queue. Consequently, all traditional models provide the average saturation headway and flow rate. However, the uncertainty that characterises driving behaviour, prompts researchers to search for more representative tools such as micro simulation models. Generally, recent studies emphasize on the stochastic nature of discharge headways. Therefore, many models have been proposed, describing the distribution of the phenomenon. Niittymäki and Pursula [17] used both the HCM and simulation to update Finland's basic saturation flow values. They resulted in a value of 1.940 pc/h/through-lane. Jin and his partners [18] proposed a model of normal-logarithmic distribution, which depends on vehicles place in the queue. Queue length may affect saturation flow because the discharge headway may decrease in a long green phase. The fact implies that saturation headways of long queues may be lower of those estimated from the first 12 vehicles [10].

All past research proves that there is a wide range of deviation between measurements of saturation flow and suggested values of the HCM in different locations. Apart from these fluctuations, a number of studies prove that different measurement methods may lead to

different results of saturation headways. Therefore, the nature of queue and the stochastic nature of the discharge process should be deeply comprehensible in order to use the most adequate technique.

### 3 Methodology

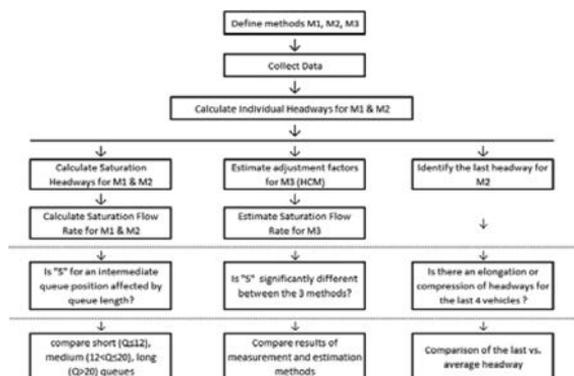


Figure 1 Research methodology

The flow of tasks for the present research is represented in detail in Figure 1. Research includes 3 basic layers; data collection and processing, formulation of the most significant concerns of the study and statistical analyses, tests and answers in the last phase of the work.

#### 3.1 Intersection description

Data was collected in the signalized junction of Karamanli Avenue with 25<sup>th</sup> of March, where the researchers measure headways on a through lane of the approach of Karamanli Av. It is a main arterial street, where the approach has lane width equal to 3,5 m, illegal parking, almost zero grade, a bus stop into the distance of 75 m from the signal and a left-turn lane.

#### 3.2 Data Collection and Survey Method

The data were collected with a hand held camera during morning and evening peak hours. The study was designed to be consistent with HCM data collection method. Every vehicle was considered discharged when its rear axle passed the stop line. The recording of the time points of the discharges attained through a software for processing videotapes with a chronometer with precision of 1/100 second. All the data from the videotapes were collected from one researcher to minimize biases due to different perceptions.

In every circle of the signal the measurement started when the first vehicle passed the stop line. Vehicle's discharge time was split in every 4<sup>th</sup> vehicle of the queue (e.g. the elapsed time for the 4<sup>th</sup>, 8<sup>th</sup>, 12<sup>th</sup> etc.). In this way apart from being consistent with the HCM method, the research managed to reduce measurement errors. The measurement stopped when the rear axle of the last vehicle in the queue passed the stop line.

#### 3.3 Calculation of headways

Individual headways were calculated through the relationship below:

$$H_i = T_i - T_{i-4} / 4 \quad (1)$$

where:

- $i$  queue position,  $i = 4, 8, 12\dots$ ;
- $H_i$  average headway from  $(i-3)$  to  $(i)$  vehicles;
- $T_i$  time recorded when the rear axle of vehicle  $(i)$  passed the stopline.

The saturation headway ( $h$ ) is then the average headway beyond the first four vehicles:

$$h = (T_N - T_4) / (N - 4) \quad (2)$$

where:

- $N$  last vehicle in a queue,  $N = 8, 12\dots$ etc.

Saturation flow rate ( $s$ ) is computed through the relationship:

$$s = 3600 / h \quad (3)$$

## 4 Saturation headways

In order to reach the objectives of the present study a number of statistical comparisons were made. Table 1 shows the number of observations for headways and the number of observations for queues length expressed with the number of vehicles in the queue for each measuring method.

**Table 1** Number of observations for headways and type of queues

Headways	M1	M2	Queue	M1	M2
H4	132	132	$Q \leq 12$	132	10
H8	132	132	$12 < Q \leq 20$	-	114
H12	132	132	$Q > 20$	-	8
H16	-	122	-	-	-
H20	-	60	-	-	-
H24	-	8	-	-	-

Firstly, the average saturation headways ( $h$ ) are computed for methods M1 and M2, regardless of the queue size. The value of M3 is estimated from HCM 2000. Subsequently, saturation flow rates ( $s$ ) were derived through Equation 3. Two-way t-test between the  $h$  estimations for M1 and M2, regardless the type of queue, showed that they are not significantly different in a significance level of 95%. On the other hand, the estimated value of the method M3 differs significantly from field measurement methods (Table 2).

**Table 2** Basic data analysis

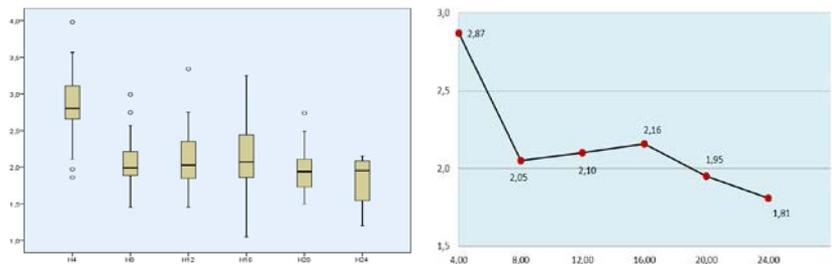
Method	$h$ [s]	Std. dev. [s]	Observations	$S$ [pc/h/ln]
M1	2,0794	0,20676	132	1731
M2	2,0895	0,20588	132	1722
M3	2.3245	-	-	1549

The results of the application of methods M1 and M2, depending on queue's size are presented in Table 3. In both methods long queues present significant differences in headways than short ones. Furthermore, the differences between M1 and M2 increase as the length of queue increases. Contrary to Bonneson [19] and Li & Prevedouros [10], study queue size appears to be a strong measure of pressure to the headways, a fact that is directly correlated to Greek driver's behaviour.

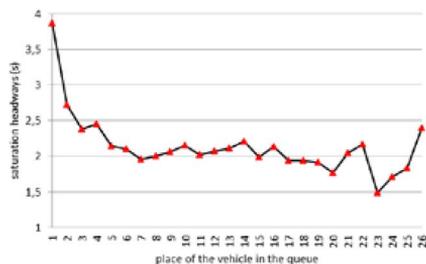
**Table 3** Basic data analysis

Queue	M1's h[s]	M2's [s]
short	2,095	2,095
medium	2,078	2,091
long	2,075	1,941

The means and standard deviations of headways in method M2 are displayed in Figure 2 which shows that the minimum headway is reached between the 5<sup>th</sup> and the 8<sup>th</sup> vehicle, as the HCM implies. The difference from HCM is that from that point on headways don't obtain a stable value. Figure 3 proves that, contrary to the HCM, after the 7<sup>th</sup> vehicle the fluctuations of headways are large and become larger after the 20<sup>th</sup> vehicle. Therefore, headways don't reach a stable value and the diagram cannot be smoothed to fit in HCM. In long queues driving behaviour seems to be so unpredictable that headways cannot be simulated according HCM suggestions. The similarities in driving behaviour between Greek and American drivers are obvious.



**Figure 2** Means and std. dev. of headways in method M2



**Figure 3** Analytical diagram of the saturation headways

According to Figure 4, the saturation flow rate obtains a first peak between the 5<sup>th</sup> and the 12<sup>th</sup> vehicle in the queue. Afterwards, its value reduces progressively and obtains its minimum value between the 12<sup>th</sup> and 16<sup>th</sup> vehicle. After this point, it starts increasing once again.

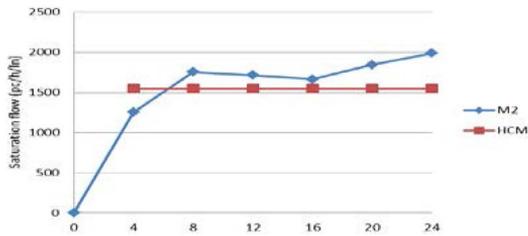


Figure 4 Saturation flow rate in method M2 and M3 (HCM)

## 5 Headway elongation/compression

The investigation of the potential elongation or compression derives through the examination of headways after the 12<sup>th</sup> vehicle. The results of t-tests show that the observed last headway is significantly different from the preceding average when the last headway refers to the 16<sup>th</sup> vehicle of the queue and also to the 24<sup>th</sup> one. In the first case the headway appears to be much higher than the average headway of the previous vehicles and in the second one the headway is smaller than that of the preceding vehicles. The traffic analysis of this approach is inconsistent with the HCM, in which it is essentially assumed that the saturation headway remains stable until the end of a standing queue. All these elements lead to the conclusions that when the standing vehicles are 13 to 16 drivers don't feel so much pressure to pass through the junction resulting in elongated headways. On the other hand, the last four drivers of a long queue (>20 vehicles) compress their headways to take advantage of the expiring green.

## 6 Conclusions

The results of the present study derived from a detailed analysis of headways on short, medium and long queues with heavy random arrivals at a busy approach of one of Thessaloniki's main central arterial roads and are outlined below.

- Saturation flow rate values deriving from HCM are significantly lower from the saturation flow rate calculated from field measurements, by methods M1 and M2. The differences in driving behaviour and in roadway's environment between Greece and USA are undeniable.
- Contrary to the HCM, even though saturation headway reaches its minimum value between the fifth and 12<sup>th</sup> vehicles, it does not obtain a stable value from that point on.
- In long queues both methods M1 and M2 provide smaller values of saturation headways than in short queues. Queue size appears to be a strong measure of pressure to the headways, a fact that is directly correlated to Greek driver's behaviour.
- Long queues present significantly different results with the use of the two methods M1 and M2. Further research must be carried out to conclude which of these methods is the most appropriate.
- In short queues drivers don't feel so much pressure to pass through the junction resulting in elongated headways. On the other hand, in long queues drivers compress their headways to take advantage of the expiring green.

All these conclusions lead the present research to suggest field measurements for saturation headways in Greece and additionally, different treatment between short and long queues through different methodologies of measurements. Future endeavours on this subject include the enrichment of the databases with data both in measurements in the same junction and in other intersection approaches, which will reduce potential local effects from this single approach analysis.

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