Determination of Basic Saturation Flow Rate in Istanbul

Süleyman Dündar*, Kemal Selçuk Öğüt**‡

* Istanbul Technical University, Graduate School of Science, Engineering and Technology, 34469, Istanbul/Turkey, dundar23@yahoo.com.

** Istanbul Technical University, Department of Civil Engineering 34469, Istanbul/Turkey,

oguts@itu.edu.tr.

‡ Kemal Selçuk ÖĞÜT, oguts@itu.edu.tr, Tel: +90 212 285 3663, ** ITU, Department of Civil Eng. 34469, Istanbul

Received: 20.10.2017 Accepted: 09.02.2018

Abstract- In traffic signal operations, the saturation flow rate is one of the key parameter for the calculation of signal timing. The saturation flow rate for different type of roads is simply calculated by multiplying the basic saturation flow rate, which is determined for predefined road and flow conditions with site factors. The aim of this study is to calculate the basic saturation flow rate in Istanbul with the help of field data. This calculation is based on the evaluation of vehicles' headways at signalized intersection.

The field study is conducted at 23 signalized intersections having basic conditions and 18,311 vehicle headways are analyzed. The initial calculations in this study are the determination of the saturation flow regions, in other word from which vehicle in the queue does the saturation flow start. It is found that the saturated headway starts from 2nd to 8th vehicle while the saturated headway is determined as 1.9 seconds, which is equivalent to 1,894 passenger cars unit per hour per lane as basic saturation flow rate.

Keywords Signalized intersection, Saturated headway, Saturation flow rate, Basic saturation flow rate.

1. Introduction

The increase of population and car ownership causes dramatic traffic jam especially in the cities of developing countries due to the lack of sufficient transportation infrastructure. The intersections, where traffic flows from different directions join, are the most affected areas from this traffic jam. These areas are not only the bottlenecks of the road network, but also critical road sections with high risk of traffic accident.

As the intersections are crucial areas in the road network, many studies have been focused on those areas since the mid-20th Century [1-10].

When the traffic volumes of intersected roads reach to a threshold value, the design of the signalization system offers more efficient and safer solution. The green and red intervals at a signalized intersection depend on traffic volume, saturation flow rate (SFR), lost time and delay. SFR is defined as the max number of vehicles per hour per lane that could pass through a signalized intersection if the green signal was displayed for the full hour continuously. Several researchers [2, 11-15] studied the SFR, which is mainly affected by the characteristics of drivers and environment conditions. SFR can be calculated by multiplying all the factors of variables that affect it by basic saturation flow rate (BSFR). BSFR is determined for default road and operation conditions.

The aim of this study is to determine the basic saturation flow rate (BSFR) in Istanbul, which has 15 million residents and more than 2,000 signalized intersections, making it, one of the mega cities of developing countries.

2. Saturation Flow Rate and Saturated Headway

SFR, which is a fundamental parameter to determine signalized intersection capacity, can be calculated by the average saturated headway (SH), which can directly be measured with field study. The mathematical relation between SFR (S) and SH (h_s) is as follows:

$$S = 3600/h_s \qquad (1)$$

When a vehicle in the queue starts crossing the stop line (or any other reference line) at a signalized intersection after the signal turns green, the departure headway (discharge headway) is the time that elapses between consecutive vehicles. The departure headways quickly decrease for the first few vehicles, and then a constant average departure headway is reached. This constant average departure headway is defined as SH.

First vehicle departure headway in the queue is the time until the first vehicle's rear wheels cross the stop line. The second vehicle departure headway is the elapsed time between the crossings of the first vehicle's rear wheels and the second vehicle's rear wheels over the stop line. The driver of the vehicle needs to react to the signal change and accelerate. The second vehicle moves faster than the first one by crossing the stop line, because of the greater distance to accelerate. The third and fourth vehicles perform a similar procedure, each achieving a slightly lower departure headway than the preceding vehicle. The decrease of departure headway terminates after few vehicles and the departure headway spreads around a constant value which is named as SH.

SFR, which can be calculated with the help of SH, has attracted attention of several researchers all over the world since 1947 [16], as given in Table 1.

From Table 1, it is seen that the range of SFR for through movement changes between 2,222 vehicles per hour per lane (vehphpl) [27] and 1,232 vehphpl [22]. Moreover, the effects of driver behaviours are modelled in Turkey, by determining the SFR between 1,110 and 1,829 vehphpl [32].

As the SFR is affected by geometrical and operating conditions, its base value, BSFR, is determined for default conditions such as:

- Lane width of 3.60 m.
- A flat grade (between ± 2 %).
- No heavy vehicles, only passenger cars.
- No parking on the approach within 75 m upstream from the stop lane.
- No bus stop on the approach within 75 m upstream and downstream from the stop lane.
- No pedestrians and bicycles crossing during vehicle green.
- Located outside of central business district.

One of the initial studies conducted on BSFR was published in 1950 [1] that suggested 1,500 passenger cars unit per hour per lane (pcuphpl) for BSFR which was later revised as 1,800 pcuphpl in 1965 [33] and as 1,900 pcuphpl in 1997 which is not changed until today [10, 34]. Several researches determined that local conditions can change BSFR, which is calculated as 2246 pcuphpl in South Africa [15], 1773 and 1535 pcuphpl in China [35,36].

Table 1. Overview of SFR studies.

Study	Country	Published year	SH (sec)	SFR (vehphpl)
Greenshields et al [16]	USA	1947	2.10	1,714
Webster and Cobbe [2]	England	1966	2.05	1,756
Gerlough and Wagner [17]	USA	1967	2.30	1,565
Miller [18]	Australia	1968	2.11	1,710
Branston and Van Zilen [3]	England	1978	2.06	1,750
Branston [19]	England	1979	2.05	1,757
Akova [20]	Turkey	1979	2.50	1,440
Kimber and Semmens [21]	England	1982	1.86	1,935
Bhattacharya et al. [22]	India	1982	2.92	1,232
Lee and Chen [11]	USA	1986	1.90	1,895
Shoukry and Huzayyin [23]	Egypt	1986	2.23	1,617
Coeymans and Meely [24]	Chile	1988	2.25	1,603
De Andrade [25]	Brazil	1988	2.17	1,660
Hussain [5]	Malaysia	1990	1.85	1,945
Stanić [26]	Serbia	1991	1.98	1,818
Al-Ghamdi [27]	Saudi Arabia	1999	1.62	2,222
German Highway Capacity Manual [28]	Germany	2001	1.80	2,000
Lee and Do [14]	South Korea	2002	1.82	1,978
Čelar [29]	Serbia	2007	1.86	1,935
Çalışkanelli [30]	Turkey	2010	2.43	1,480
Polat et al. [31]	Turkey	2015	2.13	1,687

3. Field Study

As the aim of this study is to determine the BSFR, the intersections approaches with default conditions, as given in the previous section, are selected for data collection. However, the default values of the lane width is determined as 3.5 m instead of 3.6 m due to its common usage in Istanbul.

3.1. Determination of Intersections and Data Collections

Twenty-seven different signalized approaches across Istanbul were selected for our study by taking into account the presence of long queues, which are needed for the calculation of the SH. Sixteen of these approaches have two lanes, seven have three lanes and four have four lanes. From forty-nine lanes located on these intersections, the departure headway data were collected during weekday peak periods (07:00 to 09:00 and 17:00 to 19:00) where there were no jam conditions on the downstream flow direction. The traffic data were collected manually with the help of a stopwatch in all these approaches. The twenty-three different signalized intersections with default conditions are determined in all of the selected intersections.

The lane positions at each approach are defined according to the total number of lanes in the lane groups as shown in Table 2.

Table 2. Lane positions and symbols of analyzed lanes.

Number of lanes in the approaches	Lane position (LP)	Lane symbol (LS)
2 lanes	Left	L_{II}
	Right	R_{II}
3 lanes	Left	L_{III}
	Middle	M_{III}
	Right	R_{III}
4 lanes	Left	L_{IV}
	Left Middle	LM_{IV}
	Right Middle	RM_{IV}
	Right	R_{IV}

The intersection numbers (given by İstanbul Metropolitan Municipality), types of studied signalized intersection, selected approach directions, number of lanes and LS of observed lanes are given in Table 3. The headway analysis includes 20,250 vehicles, and 18,311 quality headway data. For each vehicle position in the queu, if the headway is observed more than 20 times, it is named as quality headway and included to the study. All quality data were collected during 1,579 cycles. Data were collected from all through lanes excluding shared lane (lanes having "through and right turns" and "through and left turns") at the movement groups for each approach.

3.2. Determination of the Saturated Headway

In order to calculate the SH, the first step is to determine the rank of queued vehicles from which the SH started. The ANOVA test is applied to determine this rank at 5% level of significance. The data groups are determined according to vehicle ranks in the queue. The headways of first vehicles in the queue formed first group, the headway of second vehicles in the queue formed second group and so on. ANOVA test is performed initially with all groups. If F_{sta} is found greater than F_{cri}, the first groups is excluded from data set and the ANOVA test is performed for a second time, this elimination of groups is performed from first to last queued vehicles and stopped when F_{sta} is smaller than F_{cri}. The statistical basis for the ANOVA test is the hypothesis H_0 that the vehicle rank does not have any statistical impact on the departure headways.

Previous studies commonly indicated that the departure headway would converge to SH from 3rd to 6th queued vehicle [10, 16]. Initially, the SH region was individually determined to be based on lanes in our study. The queue headway rank of the first vehicle at SH area is determined for all approaches separately. The percentage of the rank of first SH are shown in Table 4 for two lanes, three lanes and four lanes.

The SH region varies from 2nd to 7th vehicle for 2-lane, from 2nd to 8th for 3-lane and from 2nd to 5th vehicle for 4-lane approaches as given in Table 4. It can be said that the starting position of the SH varied from approach to approach and even by the position of the lane.

In order to calculate the BSFR for an approach, it is necessary to determine if the SHs of each lane on this approach are statically similar. ANOVA test is applied to determine the statistical similarity of SH of each lane on an approach as seen in Table 5. If the SHs of each lane are statistically the same for an approach, the null hypothesis will be accepted, while p-value will be greater than 5%.

As shown in Table 5, the SHs are statistically same when the number of lanes of an approach is two. However, for the approaches with three lanes, the SHs of three lanes are statistically equal to each other on the 67% of the approaches.

For the approaches with four lanes, the SH of the right lane is always higher than the three others due to the frequently stops of taxi and minibuses to pick-up and drop-off passengers. On the other hand, when three lanes of these approaches are analysed, the SHs of these three lanes are equal to each other on the 67% of the approaches.

The average SHs for the lane position at two, three and four lanes approaches are given in Table 6, where it is seen that all the lanes average SHs are extremely close to each other and the lane position does not affect the SHs

Table 3. Data collection at signalized intersections for basic saturation flow rate.

Intersection number (IN)	Type of intersection	Observed approach		Observed lanes
		Direction	# of lanes	
1119	3-leg	Northwest	2	L_{II}
1119	3-leg	Southeast	2	L_{II} and R_{II}
1121	3-leg	Northwest	2	L_{II}
1155	Only pedestrian	Northwest	4	L_{IV}, ML_{IV} and MR_{IV}
1157	Only pedestrian	Northwest	4	L_{IV}, ML_{IV} and MR_{IV}
1192	3-leg	Southeast	4	L_{IV} and ML_{IV}
1211	3-leg	South	2	L_{II} and R_{II}
1320	3-leg	South	2	L_{II} and R_{II}
1380	3-leg	Southeast	4	L_{IV}, ML_{IV} and MR_{IV}
1832	3-leg	Southeast	2	L_{II} and R_{II}
1837	Only pedestrian	North	2	L_{II}
1850	3-leg	Southeast	3	L_{III}
1951	3-leg	North	2	L_{II} and R_{II}
2204	3-leg	Southwest	3	L_{III} and M_{III}
2242	3-leg	East	3	L_{III}, M_{III} and R_{III}
2262	3-leg	North	3	L_{III}, M_{III} and R_{III}
2271	3-leg	Northeast	2	L_{II}
2278	3-leg	Northeast	3	L_{III} and M_{III}
2278	3-leg	Southwest	3	L_{III}, M_{III} and R_{III}
2280	3-leg	Northeast	2	L_{II}
2280	3-leg	Southwest	2	L_{II} and R_{II}
3589	Only pedestrian	Southwest	3	L_{III} and R_{III}
3662	4-leg	Southwest	2	L_{II}
3662	4-leg	Northeast	2	L_{II}
3671	3-leg	South	2	L_{II}
3673	Only pedestrian	Northeast	2	L_{II}
3974	4-leg	Southwest	2	L_{II}

Table 4. Lane positions and symbols of analyzed lanes.

Number of lanes	1st saturated veh.	%
2 lanes	2nd	9
	3rd	50
	4th	36
	5th	0
	5th +	5
	Total	100
3 lanes	2nd	19
	3rd	50
	4th	13
	5th	13
	5th +	5
	Total	100
4 lanes	2nd	18
	3rd	46
	4th	18
	5th	18
	5th +	0
	Total	100

Table 5. ANOVA tests results for the similarity of the SHs of lanes.

Number of lanes	IN	Direction	SH	P-value
2 lanes	1119	SE	1.93	0.16
	1211	S	1.97	0.27
	1320	S	1.89	0.09
	1832	SE	1.86	0.07
	1951	N	1.77	0.22
	2280	SW	1.92	0.53
3 lanes	2242	E	1.95	0.94
	2262	N	1.88	0.16
	2278	SW	1.86	0.01
4 lanes*	1155	NW	1.96	0.37
	1157	NW	1.85	0.04
	1380	SE	1.88	0.80

* *4th lane (R_{IV}) data is not available, due to the frequently stops of taxis and minibuses.*

.

Table 6. Results of average headways.

Number of lanes	Position of all lanes	Number of observed lanes	Average SH per lane	Average SH per approach
2 lanes	L_{II}	16	1.87	1.88
	R_{II}	6	1.92	
3 lanes	L_{III}	7	1.90	1.91
	M_{III}	6	1.91	
	R_{III}	3	1.95	
4 lanes	L_{IV}	4	1.88	1.89
	LM_{IV}	4	1.91	
	RM_{IV}	3	1.90	

3.3. Determination of BSFR

The BSFR is the reciprocal of average of the SH vehicles. The BSFRs for through lanes are calculated between 1,800 pcuphpl and 2,045 pcuphpl, with the average is 1,894 pcuphpl, which is exceptionally close to the estimation of Highway Capacity Manual [10]. The frequency histogram of BSFRs is given in Figure 1.

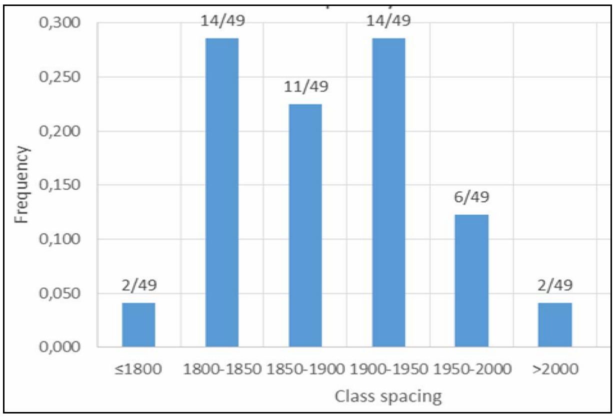

Figure 1. Histogram of BSFRs of observed lanes.

4. Conclusion

Using the survey of forty-nine lanes of signalized intersections in Istanbul, this study focuses on the determination of the basic saturation flow rate for through movements. The basic saturation flow rates are calculated with the help of SHs, which are obtained by field study.

The initial study for the calculation of SH is the identification of its interval. ANOVA test is performed to determine from which vehicle of the queue, the SH is started. It is calculated that the rank of queued vehicle from which the SH started, changes from 2 to 8 for different lanes.

When the SHs for each lane are calculated, their changes with respect to the number of lanes of an approach are studied. It is determined that when the number of lanes of an approach increases, the similarity of SH of each lane decreases.

Finally, the average basic saturation flow rate is calculated as 1,894 pcuphpl, which is extremely similar to the assumption of Highway Capacity Manual [10] 1900 pcuphpl. Moreover, the standard deviation of basic saturation flow rate is found extremely small among lanes. (61 pcuphpl).

References

[1] Transportation Research Board, Highway Capacity Manual, HRB and the Bureau of Public Roads, Washington, DC, USA, 1950.

[2] Webster, F. V. and Cobbe, B. M., “Traffic Signals”, Technical Paper 56, HMSO, London, England, 1966.

[3] Branston, D. and Van Zuylen, H., “The Estimation of Saturation Flow, Effective Green Time and Passenger Car Equivalents at Traffic Signals by Multiple Linear Regression”, Transportation Research, Vol. 12 (1), 47–53, 1978

[4] Akçelik, R., “Traffic Signals: Capacity and Timing Analysis Research Report ARR 123”, Australian Road Research Board, Vermont, South Victoria, 1981.

[5] Hussain, A. M., “Determination of Saturation Flows at Signalized Intersection in Malaysian Urban Areas”, Proceedings of the Sixth Conference, Road Engineering Association of Asia and Australasia, [CD-ROM] Kuala Lumpur, Malaysia, 1990.

[6] Turner J. and Harahap, G., “Simplified Saturation Flow Data Collection Methods”, Transportation Research Laboratory, England, 1993.

[7] Bonneson, P.E., Nevers, B. and J. Zegeer, J., “Guidelines for Quantifying the Influence of Area Type and Other Factors on Saturation Flow Rate”, Texas Transportation Institute, College Station, Texas, USA, 2005.

[8] Rahman, M., Nur-ud-deen, S. A. and Hassan, T., “Comparison of Saturation Flow Rate at Signalized Intersections in Yokohama and Dhaka”, Proceedings of the Eastern Asia Society for Transportation Studies, Vol. 5, 959–966, 2005.

[9] CCG, Canadian Capacity Guide for Signalized Intersections, Institute of Transportation Engineers, Canada, 2008.

[10] Transportation Research Board, Highway Capacity Manual, National Research Council, Washington, DC, USA, 2010.

[11] Branston, D. and Gipps, P., “Some Experiences with a Multiple Regression Method of Estimating Parameters at the Traffic Departure Process”, Transportation Research, Vol. 6A, 445–458, 1981.

[12] Kimber, R.M., McDonald, H. and Hounsell, N.B., “Passenger Car Units in Saturation Flows: Concept, Definition, Derivation”, Transportation Research, Vol. 1B, 39–61, 1985.

[13] Lee, J. and Chen R. L., "Entering Headway at Signalized Intersections in a Small Metropolitan Area", Transportation Research Record 1091, 117-126, Washington, DC, USA, 1986.

[14] Lee, H.S. and Do, T.W., "Saturation Headway of Through Movement at Signalized Intersections in Urban Area", Journal of Transportation Research Society of Korea, Vol. 20, No. 5, 23-31, 2002.

[15] Bester, C. J., Meyers W.L., "Saturation Flow Rates", Proceedings of the 26th South African Transport Conference (SATC), 560-568, Johannesburg, 2007.

[16] Stanić, B., Tubić Vladan and Čelar, N., "Straight Lane Saturation Flow and Its Rate in Serbian Cities", Transport, Vol. 26, No. 3, 329-334, 2011.

[17] Gerlough, D.L., Wagner, F.A., "Improved Criteria for Traffic Signals at Individual Intersections", Highway Research Board NCHRP No.32, Washington, DC, 1967.

[18] Miller, A. J., "Australian Road Capacity Guide-Provisional Introduction and Signalized Intersections", ARR 79. Australian Road Research Board, 1968.

[19] Branston, D., "Some Factors Affecting the Capacity of Signalized Intersections", Traffic Engineering and Control 20 (8/9), 390-396, 1979.

[20] Akova, M., "Investigation of Effect of Posture, Departure and Discharge Conditions in Calculation Methods and Appropriate to the Reality of Our Country at Signalized Intersection", PhD Thesis, Istanbul Technical University, Turkey, 1979.

[21] Kimber, R. M. and Semmens, M.C., "An Experiment to Investigate Saturation Flows at Traffic Signal Junctions", Traffic Engineering and Control 23, 110-117, 1982.

[22] Bhattacharya, P. G. and Bhattacharya, A. K., "Observation and Analysis of Saturation Flow through Signalized Intersections in Calcutta", Indian Highways, 10, 11–33, 1982.

[23] Hussayin, A. S. and Shoukry, W.S., "Saturation Flow and Effective Approach Width at Signalized Intersections in Greater Cairo", 6th African Highway IRF Conference, 1986.

[24] Coeymas, J. E. and Meely, C. B., "Basic Traffic Parameters in the Case of Santiago", 1988 (Unpublished).

[25] De Andrade, J. P., "The Performance of Urban Intersections in Brazil", PhD Thesis, University of Southampton, 1988 (Unpublished).

[26] Stanić, B., "Research on Signal Timing Plan Effects at Saturation Flow", PhD Thesis, University of Belgrade, Serbian, 1991.

[27] Al-Ghamdi, A. S., "Entering Headway for Through Movements at Urban Signalized Intersections", Transportation Research Record 1678, 42-47, Washington, DC, USA, 1999.

[28] HBS, German Highway Capacity Manual, Germany, 2015.

[29] Čelar, N., "Contribution to the Survey of Design Values of Saturated Flow at Signalized Intersections", MSc Thesis, University of Belgrade, Serbian, 2007.

[30] Çalışkanelli, S.P., "Investigation of Headway Distribution of the Vehicles Departing From Signalized System at 9 Signalized Intersections in Izmir", PhD Thesis, Dokuz Eylul University, Turkey, 2010.

[31] Polat, A., Sarısoy, G. and Öğüt, K.S., "Determining of Start-up Lost Time and Saturation Flow Rate at Signalized Intersections in Small Cities", 11th Transportation Congress, 129-138, Istanbul, Turkey, 2015.

[32] Cetin, M. Murat and Y. S., "A Mathematical Model for Determining Saturation Flows", Technical Journal of Turkish Chamber of Civil Engineers, Volume 24, Number 2, April 2013, p 4759-4777, 2013.

[33] Transportation Research Board, Highway Capacity Manual, National Research Council, Washington, DC, USA, 1965.

[34] Transportation Research Board, Highway Capacity Manual, National Research Council, Washington, DC, USA, 1998.

[35] Shao, C., Rong, J. and Liu, X., "Study on the Saturation Flow Rate and Its Influence Factors at Signalized Intersections in China", 6th International Symposium on Highway Capacity and Quality of Service, Sweden, 2011.

[36] Shang, H., Zhang, Y. and Fan, L., "Heterogeneous Lanes' Saturation Flow Rates at Signalized Intersections", 9th International Conference on Traffic & Transportation Studies (ICTTS'2014), Vol. 138, 3-10, 2014.