Discharge Headway Time Distribution Model on Congested Signalized Intersections and their Operation Management: A Case Study in Baghdad City

Zainab Ahmed Alkaissi*, Ali Jabbar Kadhim**, Saja Ali

Department of Highway and Transportation Engineering, College of Engineering, Mustansiriya University, Baghdad, Iraq.

*Email: zainabalkaisi77@googlemail.com
   dr.zainabalkaisi77@uomustansiriya.edu.iq.com; Corresponding Author.

**Department of Highway and Transportation Engineering, College of Engineering, Mustansiriya University, Baghdad, Iraq.

Email: dr.alijabbar@yahoo.com

Abstract. A discharge headway time is an essential parameter in the theory of traffic flow that largely utilized in various sections of engineering transport. Discharge time headway is a necessary traffic measure used widely in the analysis of signalized intersection. This research focuses on the comprehensive analysis and regression model of vehicle discharge headway at signalized intersections and applied operation management using upstream access points. A comparison of median and mean values of discharge saturation headway indicated that the median of (2.230sec.) is less than mean of (2.5272sec.). That means the concentration of small time headways and most of drivers select headways less than the mean value which cause high risk-potential for drivers and reduced safety performance at signalized intersections. Higher values of discharge headway were found to be (4.13sec.), (3.12 sec.) and (3.08sec.) for Al-Nakhala intersection, Al-Sakhar Intersection and Bairuit Intersection respectively. The induced of upstream access management improved the saturation flow rate to (28%) for Al-Sakhar Intersection and (31%) for Al-Nakhala Intersection that indicated normal traffic operation with less congestion to a better operation conditions.

Key words: Discharge headway; Saturation flow; Signalized intersection; Logistic model; Access Management.
1. Introduction

The estimation of capacity of approach lane or lane groups for signalized intersections are predominating required for the performance assessment. The capacity evaluation is an important component in the design, operation, management, and planning of transportation system.

Discharge headways at signalized intersections are defined as the time intervals between two successive vehicles crossing a predetermined reference line (stop line) at the intersections. It can be described in terms of the driver behavior (their response) during queue discharge (Akçelik and Besley, 2002). Spacing between vehicle in queue and queue discharge speed are as shown in, Eq.(1) (Li and Prevedouros, 2002):

\[ h_s = t_r + \frac{L_{ij}}{v_s} \]  

where:

- \( h_s \) is the headway discharge vehicles (s);
- \( t_r \) the response of driver in time (s);
- \( L_{ij} \) length of queue space per vehicle (including vehicle length, m);
- \( v_s \) the speed of queued vehicle in (m/s). From Eq. [1],

Due to the variety of driver behavior (response time and variation in the length of queue space), the queue discharge headway is considered as a random variable [3]. In order to predict the saturation headway, the average headway of queue discharge is estimated as in Eq.(2):

\[ \overline{h_s} = \frac{1}{n} \sum_{i=1}^{n} h_{si} \]  

where:

- \( \overline{h_s} \) is the average headway(s) of queue discharge; which can be considered as the estimation of saturation headway \( h \).
- \( h_{si} \) is the vehicle (i) headway in the queue, \( i=1,2,3,... \ n \) (n is the sample size). Therefore, the traditional saturation flow rate is determined by the headways of queue discharge, see Eq. (3):

\[ S = \frac{3600}{\overline{h_s}} \]  

where:

- \( S \) is depicted the saturation flow rate (veh/h).

The headway \( (i_1) \) is the time interval between the opening of the green signal and the instant vehicle passing the curb line. The headway\( (i_2) \) is the time interval between the first and the second vehicle crossing the curb line. Successive headways are then scheme as in Figure 1. The headway\( (i_1) \) will be relatively longer since it includes the reaction time of the driver and the time necessary to accelerate. The headway\( (i_2) \) will be comparatively lower because the second driver can interfere his/her response time with that of the first driver’s. After passing of several vehicles, the headway will remain constant.
As mentioned previously, the headway will be more than (h), particularly for the first several vehicles. The difference between the actual headway and h for the vehicle i is designated as \( e_i \) as depicted in Figure 1. Figure 2 shows, in a time-space diagram, a perfectly regular discharge of passenger cars from a standing queue with all cars accelerating uniformly at the same rate from the stopping position to a constant speed.

**Figure 1.** Headways Departing Signal.

**Figure 2.** Perfectly Regular Discharge from Standing Queue, with Uniform Acceleration (Akçelik and Besley, 2002).
Arasan and Vedagiri (2006) established a considerable increase in the saturation flow rate (measured in PCU per meter width) with an increment in the width of the approach road. (Hossain, 2001) predicted a model relating the influence of approach width, the proportions of turning vehicles, the percentage of non-motorized and heavy vehicles on saturation flow. (Leong, 1964) found that the left turning vehicles and right turning vehicles have a considerable effect on saturation flow.

(Alkaissi, Z A, 2018) used the Logistic distribution function to describe the headway time for Palestine arterial street. A scale parameter from 1.5 to 0.85 is determined. Also the variation of time headway for studied links; (link1) and link(2) with different land uses are obtained.

2. Site Selection

Palestine street located in Eastern Baghdad is run parallel and to the west of Army Canal Street starting from Al Mustanssiriya through Bairut intersection to Maysalon intersection near Al Mustansiriyah zone. Which is considered as one of most important arterial roads in Baghdad city passing through central business district area as shown in Figure 3.

Figure 3. Study Area: Urban Arterial Palestine Street. Eastern Baghdad.
3. Data Collection

Data used in this research have been collected on three signalized intersections of Palestine street; see Figure 4:
1. AL-Nakhala Intersection (Bab ALMoatham Intersection).
2. Al-Sakhara Intersection.
3. Bairuit Intersection.

Data were collected manually as shown in Plate (1) on working days during the evening peak period (1:00-2:00 pm) on Wednesday (3 January, 2018), Monday (5 February, 2018), Tuesday (6 March, 2018), Tuesday (17 April, 2018), Wednesday (2 May, 2018) and Monday (4 June, 2018). To discard the impact of start-up and acceleration on the saturation flow rate, the first fourth vehicle (ith) headways in each signal cycle were removed from the data. Plate (1) shows field data recording of saturation headway for Al-Nakhala Signalized Intersection.

Plate 1. Field Collection Data at Al-Nakhala Intersection.

The collection of field data is done with a stopwatch as shown in Plate (1). Only the times of the 4th vehicle that crosses the stop bar, the stopped vehicle in the end of queue, and the end of green (in case the signal is in overflow conditions and the last stopped vehicle is never accomplished) is needed. The number (vehicle position in the queue) of the vehicle that stopped at the end of queue is needed. Enumerated Vehicles shouldn't be determined till they pass the stop bar. The right or left turn lane is inspected, only if estimate the vehicles that clear the approach intersection if they are delayed waiting for conflicting traffic or pedestrians. The cycle time should be eliminated by crossing the cycle out on the form, if vehicles are delayed because of buses, emergency vehicles, stalled vehicles, downstream intersection queues or other disruptions. As long as there are eight or more vehicles totally in the stopped queue, a cycle can be used to calculate discharge saturation headway.
4. Results and Discussions

4.1 Discharge Headway

For each of the three selected signalized intersections; AL-Nakhala Intersection (Bab ALMoatham Intersection), Al-Sakhara Intersection and Bairuit Intersection the saturation discharge headway have been estimated and analyzed during peak evening period (1:00-2:00)p.m. as shown in Figures 4, 5 and 6 respectively. A proper estimation of saturation headway at signalized intersections leads to an appropriate appraisal of capacity. The average discharge headway of (2.37 sec.), (1.87 sec.) and (2.43 sec.) for Al-Nakhala intersection, Al-Sakhara Intersection and Bairuit Intersection respectively was obtained. This explored the traffic operation conditions with more heavier congested conditions for Al-Nakhala intersection, Al-Sakhara Intersection and Bairuit Intersection. The differences between each signalized intersection for saturation time headway during the peak evening period (1:00-2:00 p.m.) could be attributed to the driver behavior, since different motivations of drivers are induced.

\[ \text{Discharge Headway (sec.)} \]

\[ \text{No. of Cycles} \]

\[ \text{Al-Nakhala Intersection} \]

---

**Figure 4.** Discharge Saturation headway for Al-Nakhala Intersection (January, 2018).
Figure 5. Discharge Saturation headway for Al-Sakhara Intersection (January, 2018).

Figure 6. Discharge Saturation headway for Bairuit Intersection (January, 2018).
4.2 Time Variations of Discharge Saturation Headway

In order to get more reliable data of headway discharge pattern, field data for different months (January, February, March, April, May, and June) 2018 were collected and the distribution pattern for variations are depicted in Figure 7. Higher values of discharge headway of (4.13 sec.), (3.12 sec.) and (3.08 sec.) are obtained for Al-Nakhala intersection, Al-Sakhara Intersection and Bairuit Intersection respectively at February (2018) which indicated a normal traffic operation with less congestion conditions.

Figure 8 presents the flow rate during saturation conditions for selected three studied signalized intersections in this research, since the saturation of flow rate is considered as major element for determining the capacity of intersection. The flow rate of saturation were estimated as (1519 veh/hr/ln), (1923 veh/hr/ln) and (1481 veh/hr/ln) for Al-Nakhala intersection, Al-Sakhara Intersection and Bairuit Intersection respectively. Figure 9 shows the time variations of field saturation flow for signalized intersections.

![Figure 7. Time Variations of Mean Departure Headway for Signalized Intersections.](image-url)
4.3 Discharge Headway Time Distribution

According to the field collected data for the three signalized intersections; Al-Nakhala intersection, Al-Sakhara Intersection and Bairuit Intersection and based on the statistical test results of the recorded data for discharge saturation headway, the frequency distribution were predicted using SPSS (SPSS ver.21 software of statistical test) as depicted in Figure 9. The fundamental statistical characteristics of discharge saturation headway field data are presented in Table 1. As shown from the obtained results and comparison of median and mean values of discharge saturation headway indicated that the median of (2.230) is less than the mean of (2.527sec.). That means concentration of small time headways and most of drivers select headways less than mean value which causes high risk-potential for drivers and reduces safety performance at signalized intersections.

Figure 10 presents the normal Q-Q plot which shows good fit linear pattern with insignificant deviation from the best line fit on the probability plot. The normal distribution appears to be an appropriate distribution for describing saturation headway time data.
Figure 9. Time Headway Distribution for Signalised intersections.

Table 1. Descriptive Statistics of discharge Saturation Headway.

| Descriptive                        | Statistic | Std. Error |
|------------------------------------|-----------|------------|
| Mean                               | 2.5272    | .15693     |
| 95% Confidence Interval for Mean   |           |            |
| Lower Bound                        | 2.2132    |            |
| Upper Bound                        | 2.8412    |            |
| 5% Trimmed Mean                    | 2.3819    |            |
| Median                             | 2.2300    |            |
| Variance                           | 1.478     |            |
| Std. Deviation                     | 1.21557   |            |
| Minimum                            | .98       |            |
| Maximum                            | 7.84      |            |
| Range                              | 6.86      |            |
Interquartile Range | 1.12 |
|-------------------|------|
| Skewness          | 2.328 .309 |
| Kurtosis          | 6.998 .608 |

Figure 10. Normal Q-Q Plot for Discharge Saturation Headway.

4.4 Discharge Headway Distribution Model
The probability density function for discharge saturation headway was predicted for signalized intersections in order to determine the appropriate distribution function that described the saturation headway time more precisely. Figure 11 shows the probability density function for the studied signalized intersections. It can be observed that the shape is skewed to the right. The Logistic distribution function with scale parameter of 0.9 demonstrated the discharge saturation headway distributions. Table 2. presents the normality test for adopted distribution probability function for discharge saturation headway time.

Also this research presented two function distribution for cumulative density function namely; exponential and Gamma CD functions as presented in Figure 9. Investigations and validations were accordingly made for these functions and additional field data have been recorded. Figure 12 illustrated the comparison between the recorded surveyed data and theoretical functions.
Figure 11. PDF of Time Discharge Headway Distribution for Signalized Intersections.

Table 2. Normality test for Probability Distribution Function.

| Tests of Normality | Kolmogorov-Smirnov\(^a\) | Shapiro-Wilk |
|-------------------|------------------------|-------------|
| Statistic         | df         | Sig.       | Statistic | df      | Sig.     |
| Headway           | .159       | 60         | .001      | .781    | 60       | .000     |

a. Lilliefors Significance Correction
4.5 Operation Management
The Good operation management of traffic congestion enhances efficient and safe use of road network. Its compromises a variety of techniques that reduces traffic congestion and provide a better operational flow at signalized intersection. Access points management upstream of Al-Nakhala and Al-Sakhara Intersections have been introduced as shown in Figure 13 and 14 respectively. These access points will reduce the number of conflicting left turn vehicles at intersections and improve the traffic flow during the oversaturation conditions. Also, keep in mind that the good access management results in better operational performance of road intersections, and indigent system can result from poor management access.
Figure 13. Upstream Access Point of Al-Nakhala Intersection.

Figure 14. Upstream Access Point of Al-Sakhara Intersection.
The saturation headways of Al-Sakhara and Al-Nakhala intersections with access point are smaller as compared to the studied intersections without upstream access points.

Figure 15 and Figure 16 depict the effect of access points on saturation headways for Al-Nakhala and Al-Sakhara intersections respectively. It can be observed that the induced of upstream access management improved the saturation flow rate to (28%) for Al-Sakhara Intersection and (31%) for Al-Nakhala Intersection during congestion period (February, 2018).

**Figure 15.** Effect of Upstream Access Point on Saturation Headway for Al-Sakhara Intersection.
5. Conclusions

The research presented the analysis and modeling of discharge saturation headway at (3) surveyed signalized intersections in Baghdad city; it can be drawn the following conclusions:

1. Average discharge headway about (2.37 sec.), (1.87 sec.) and (2.43 sec.) for Al-Nakhala intersection, Al-Sakhara Intersection and Bairuit Intersection respectively is obtained. This explored the traffic operation conditions with more heavy congested conditions for Al-Nakhala intersection, Al-Sakhara Intersection and Bairuit Intersection.

2. Higher values of discharge headway of about (4.13 sec.), (3.12 sec.) and (3.08 sec.) for Al-Nakhala intersection, Al-Sakhara Intersection and Bairuit Intersection respectively at February (2018) were obtained which indicated a normal traffic operation with less congestion conditions.

3. The saturation flow rate were estimated (1519 veh/hr/ln), (1923 veh/hr/ln) and (1481 veh/hr/ln) for Al-Nakhala intersection, Al-Sakhara Intersection and Bairuit Intersection respectively.

4. A comparison of median and mean values of discharge saturation headway indicated that the median of (2.230) is less than the mean of (2.5272 sec.). That means concentration of small time headways and most of drivers select headways less than mean value which causes high risk-potential of driver and reduces safety performance at signalized intersections.
5. The Logistic distribution function with scale parameter of 0.9 demonstrated the discharge saturation headway distributions and for cumulative density function namely; exponential and Gamma CD functions is presented and used to probably describe the time headway of Al-Nakhala, Al-Sakhara and Bairuit signalized intersections.

6. The saturation headways of Al-Sakhara and Al-Nakhala intersections with access point are smaller as compared to the studied intersections without upstream access points. And the induced of upstream access management improved the saturation flow rate to (28%) for Al-Sakhara Intersection and (31%) for Al-Nakhala Intersection.

Reference

[1] R. Akçelik and M. Besley, 2002. Queue discharge flow and speed models for signalized intersections, in Proceedings of the 15th International Symposium on Transportation and Traffic Theory, pp. 99–118, Pergamum, Elsevier Science, Oxford, UK.

[2] H. Li and P. D. Prevedouros, 2002. Detailed observations of saturation headways and start-up lost times, Transportation Research Record, no. 1802, pp. 44–53.

[3] Arasan, V. T., and Vedagiri, P. 2006. Estimation of Saturation Flow of Heterogeneous Traffic Using Computer Simulation. Proceedings 20th European Conference on Modelling and Simulation.

[4] Hossain, M. 2001. Estimation of saturation flow at signalised intersections of developing cities: a micro-simulation modelling approach. Transportation Research Part A, 35, 123–141.

[5] Leong, H. J. N. 1964. Some Aspects of Urban Intersection Capacity. Proceedings of Australian Road Research Board, 21(155), 305–338.

[6] Alkaissi, Z.A, 2018. Analytical Study of Headway Time Distribution on Congested Arterial: A Case Study Palestine Road in Baghdad City. International Congress and Exhibition" Sustainable Civil Infrastructures: Innovative Infrastructure Geotechnology".