Research, Development
& Technology Transfer Program

District Department of Transportation

Prevailing Saturation Flow Rate for Lane Groups in the District of Columbia

Final Report

December 17th, 2014

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Final Report

Dr. Stephen A. Arhin, P.E., PTOE and Dr. Errol C. Noel, P.E.
Howard University Transportation Research Center

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The District Department of Transportation seeks to determine its local base saturation flow rate (SFR), which will be used in the conduct of level of service analyses for signalized intersections. The first step in the process of determining the local base SFR, in accordance with the 2010 Highway Capacity Manual (HCM), is to determine the prevailing SFR for selected lane groups. This study focused on determining the prevailing SFR for the through (T), shared right and through (RT), shared left and through (LT) and exclusive left turn (L) lane groups. The study determined the prevailing SFR for the mentioned lane groups based on data collected at 67 intersections for the morning and evening peak periods. The prevailing SFR was computed based on the average headway data obtained from the field at the selected intersections. An overall mean prevailing SFR of 1,559 vehicles per hour per lane (vphpl), 1,461 vphpl, 1,526 vphpl and 1,477 vphpl was determined for the T, RT, LT, and L lane groups. These average prevailing SFRs can be used to determine the local base SFR for the city based on the procedures of HCM. This will involve the determination of the adjusted SFRs for the selected lane groups after which the local base SFR can be computed using the formula presented in this report.</td></tr>
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1 Executive Summary

Saturation flow rate (SFR) is a measure of the maximum traffic flow rate in a specific lane group on an approach of signalized intersections, and is used in operational (and planning) analysis as well as the design of signalized intersections. The default SFR is 1,900 passenger cars per hour per lane (pc/h/ln), according to the 2010 Highway Capacity Manual (HCM), which may or may not represent conditions in a specific region or jurisdiction. As a result, a local base SFR is often determined for each jurisdiction in order to accurately predict the average vehicle delays at signalized intersections, based on procedures in the HCM. Determining the prevailing SFR for lane groups is the first step in the computation of a local base SFR. The prevailing SFR is obtained from average headways measured in the field. This study determined the prevailing SFRs for specific lane groups in the District of Columbia (the District) which will be used to determine the local base SFR.

The study focused on four (4) lanes groups at 67 intersections in the District for the morning (7:30 AM to 10:30 AM) and afternoon (3:30 PM to 6:30 PM) peak hours from Monday to Friday. There were 60 selected intersections for the through lane group which were divided into zones (1 through 6). Fifteen (15) intersections were selected for the shared through and right, seven (7) intersections for the shared through and left and four (4) intersections for the exclusive left turn lane groups. Using the average headways obtained for each lane group, the prevailing SFRs were computed.

Statistical analyses were conducted on the field data obtained. The average prevailing SFR values for all lane groups in the morning peak hour period determined from local field data ranged from 1,451 to 1,577 vehicles per hour per lane (vphpl) while those for the afternoon peak hour ranged from 1,426 to 1,542 vphpl. The summary of the average prevailing SFR by lane group for morning and evening peak periods are summarized in the table below.

Lane Group	Saturation Flow Rates (vphpl)		
	AM	PM	Overall Average
Through	1,577	1,542	1,559
Through/Right	1,495	1,426	1,461
Through/Left	1,533	1,518	1,526
Left	1,451	1,503	1,477

Using the average prevailing SFRs, the local base SFR can be determined. This will involve the determination of the adjusted saturation flow rates after which the local base SFR for the District can be computed using HCM procedures.

2 Introduction

Saturation flow rate (SFR) is an important measure of the maximum traffic flow rate in a specific lane group on an approach of signalized intersections. SFR is used extensively in the operational analysis and design of signalized intersections. Assuming that an intersection's approach signal could stay green for an entire hour, and the traffic is as dense as it could reasonably be expected, then the number of vehicles that would pass through the approach during that hour is defined as the saturation flow rate (SFR). Therefore, the SFR for a signalized intersection lane group can be defined in broad terms as the maximum number of passenger car units (pcu) per hour of green that flow through a specific intersection lane group. The SFR has been integrated in many software programs for traffic operations and planning evaluations, such as the Highway Capacity Software (HCS), Synchro Studio and Transyt-7F. The calculation of vehicle delays and hence the level of service (LOS) for intersections relies on credible values of SFR. The SFR is a critical factor used in LOS analyses for signalized intersections in the methods of the Highway Capacity Manual (HCM).

SFR depends on several roadway and traffic conditions (parking, lane configuration, lane width, presence of heavy vehicles, traffic behavior, number of lanes, traffic volumes, approach grade, etc.) and can vary substantially from one jurisdiction to another. The literature reveals that the following factors influence the magnitude of the SFR:

- Traffic composition - different types of vehicles, motorized and non-motorized, with different operating performances, such as signal timing.
- Driver behavior - poor lane discipline and observation of traffic signals
- Public transport - varied mix of bus types, bus stop locations and driving styles
- Roadside activity - roadside land uses generate parking and non-transport activities that reduce effective lane width
- Speed limits
- Gradient
- Right-turn and left-turn lanes
- Number of through lanes
- Area type - central business district (CBD) or non-CBD

In the conduct of LOS analyses, a base SFR is used. A number of jurisdictions have determined a local base SFR that is representative of their respective regions. Determining a prevailing SFR of a lane group is the task taken to determine a local base SFR. The prevailing SFR is determined by using the average headway obtained from field measurement. It is the vehicle per hour per lane through a specific intersection approach and lane group.

3 Objective

This study involved determining the average prevailing SFR for four different lane groups in the District. The four lane groups used for this study are: through (T), shared right and through (RT), shared left and through (LT), and exclusive left-turn (L). The average prevailing SFRs for the lane groups will be used to compute the local base SFR.

4 Literature Review

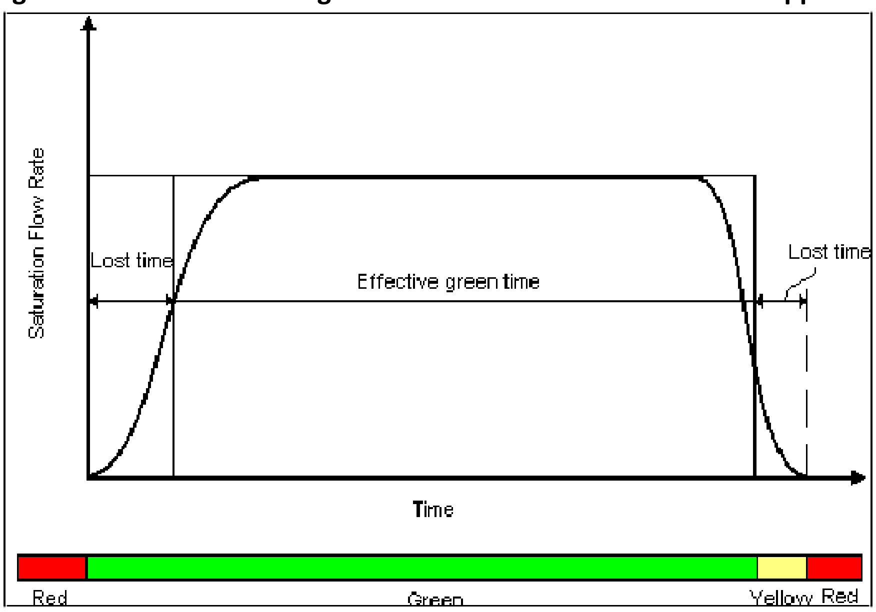
Saturation flow rate is defined as the flow rate, in vehicles per hour, that can be accommodated by a lane group, assuming that the green phase were displayed 100 percent of the time. Stated another way, g/C = 1.0 where g is the effective green time and C is the cycle length [1]. SFR is generally computed by:

$$s = \frac{3600}{h} \quad (1)$$

where
s = saturation flow rate (vphpl)
h = saturation headway (seconds/vehicle)

The default saturation headway is 1.9 seconds, which corresponds to a default base saturation of 1,900 passenger cars per hour per lane (pc/h/ln) [1]. The idealized saturation flow rate is shown in Figure 1.

Figure 1: Traffic Flow during the Green Period from a Saturated Approach



The saturation flow rate for each lane group is computed by:

$$s = s_o N f_W f_{HV} f_g f_p f_{bb} f_a f_{LU} f_{RT} f_{LT} f_{Lpb} f_{Rpb} \quad (2)$$

where
s = saturation flow rate for subject lane group (vphgpl)
s_o = ideal saturation flow rate per lane (pc/h/ln)

N = number of lanes per group
f_W = adjustment factor for lane width
f_{HV} = adjustment factor for heavy vehicles in traffic stream
f_g = adjustment factor for approach grade
f_p = adjustment factor for existence of a parking lane and parking activity adjacent to lane group
f_{bb} = adjustment factor for blocking effect of local buses that stop within intersection area
f_a = adjustment factor for area type
f_{LU} = adjustment factor for lane utilization
f_{RT} = adjustment factor for right turn in lane group
f_{LT} = adjustment factor for left turn in lane group
f_{Lpb} = pedestrian adjustment factor for left turn movements
f_{Rpb} = pedestrian-bicycle adjustment factor for right turn movement

Using Equation 2, the base saturation flow rate and the adjustment factors can be substituted to estimate the SFR of a lane group.

A study conducted in 2007 [2] showed that ideal SFR is not the same for different locations. Long [2] implied that the concept in the HCM of the base saturation flow rate being constant implies an underlying model that saturation flow rate is equal to capacity, without the involvement of other variables. Several jurisdictions have since undertaken the effort to modify the default SFR from the HCM to values that are more in line with local conditions

Bonneson et al. [3] conducted research to determine the ideal SFR for through lane movements and to develop adjustment factors that account for the effects of area type, number of lanes and presence of right-turn vehicles at signalized intersections in Florida. The research was conducted at 35 intersections that collectively reflect a range of area type, right-turn volume, number of lanes and area populations. Different effects of adjustment factors on saturation flow rate were analyzed. The adjustment factors covered right-turn vehicle percentage, lane type, area population, number of lanes, heavy vehicle percentage, traffic pressure and speed limit.

Two methods were used to determine the base saturation flow rate. The first method was based on field data collection; resulting in a base saturation flow rate of 1,918 pc/h/ln, which is equivalent to headway of 1.87 sec/veh. The second method was a test based on McMahon Data. The McMahon Data represents the passenger car saturation flow rate on the through movement approach of 12 intersections in the Florida Department of Transportation District 4. The result of their analysis was a base SFR of 1,969 pc/h/ln and headway of 1.83 sec/veh. The final base saturation flow estimate was obtained by using the weighted average of the saturation headway from the two tests. The values used to weigh the two headways were the standard deviations obtained from the two tests. This resulted in weighted average saturation headway of 1.85 sec/veh and a corresponding base saturation flow rate of 1,950 pc/h/ln. The base rate of 1,950 pc/h/ln and the adjustment factors were recommended to be used by the state of Florida.

Dunlap [4] conducted a study in 2005 to determine the appropriateness of the lower ideal SFR established by the Pennsylvania Department of Transportation District 12-0 by field measuring a sample of saturation flow rates, from which the ideal SFR was computed. The data collection was performed according to HCM's procedures. Data were collected on through, left-turn and right-turn lanes at five intersections in four different counties in southwestern Pennsylvania. The intersections selected had abnormally long queues for extended durations during the peak periods. The comparisons of ideal SFRs by county, lane type, approach grade, lane width, percentage heavy vehicles, atmospheric conditions, and time of day were analyzed using one-way ANOVA and Duncan's Test. The study concluded that ideal SFR of 1,800 pc/h/ln used in District 12-0 was ideal. However, the study determined a weighted average ideal SFR of 1701 pc/h/ln for the intersections studied.

A SFR study was conducted at 25 signalized intersections in Panama City, Republic of Panama [5] in 2006. The purpose of the study was to determine the saturation headway and saturation flow rate in Panama City. The study focused on only through lanes, while considering the effect of heavy vehicles with variations in lane widths on saturation headways. The percentages of heavy vehicles considered were 0, 10%, 20%, 30% and 40%. Forty cycles for each site were used for the statistical analysis at 95% confidence level. Field data collection for headways were conducted using the standard HCM procedures based on which a representative SFR and saturation headway for the 25 intersections were calculated using the HCM 2000 multiplicative model. The results of the analysis showed that the saturation headways from the field data were less than the default saturation headway of 1.9 seconds and that the default value of 1,900 pc/h/ln was not adequate for Panama City. A greater saturation flow rate was determined for Panama City traffic conditions. A two-way analysis of variance was also conducted to evaluate the effect of heavy vehicles and lane widths over the saturation headways, at a level of significance of 5%. The results showed that the effect of heavy vehicles and lane width on saturation headway in Panama City was significant. The interaction effect between heavy vehicles and lane width was also determined to be statistically significant.

In 2009, Zang and Chen [6] in Nanjing, China used linear regression analysis to calibrate saturation flow rate for intersections based on data obtained at nine intersections. The study focused on the impact of heavy vehicles on saturation flow rate; other factors were not considered for this research. Therefore, it was assumed that

$$s = s_o f_{HV} \qquad (3)$$

where:

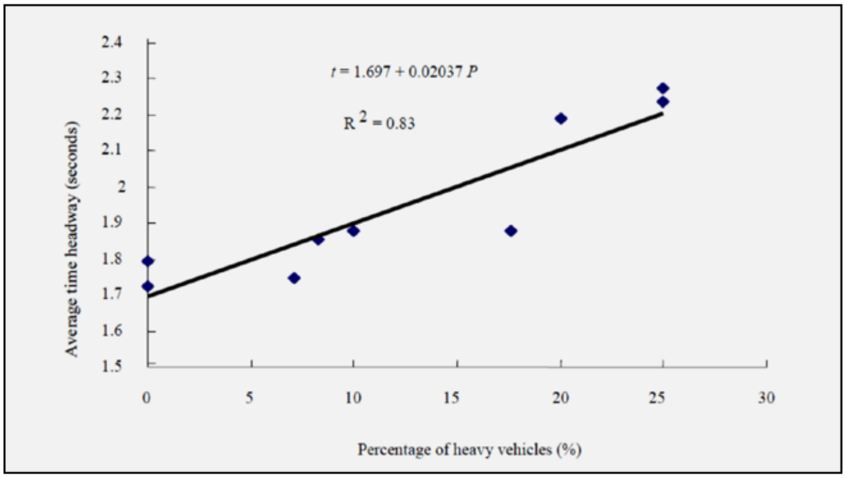
s = saturation flow rate for subject lane group (vphgpl)

s_o = ideal saturation flow rate per lane (pc/h/ln)

f_{HV} = adjustment factor for heavy vehicles in traffic stream

The study showed that heavy vehicles have a high correlation with the average headway. Figure 2 shows the resulting linear regression analysis model, where t is the average time headway (seconds) and P is the percentage of heavy vehicles (%). The *F*-test was used to confirm the significance of the regression model with a significance level of 1% (0.01). An ideal saturation flow rate of 2,121 pc/h/ln was determined for the intersections based on the resulting regression model.

Figure 2: Regression Model for Average Headway and Percentage of Heavy Vehicles [6]



Potts et al [7] conducted a study to determine the relationship between lane width and SFR at 25 signalized intersections. The critical component of the research was to determine the ideal SFR using lane width adjustment factor. The study considered 2,733 vehicles for lane widths of 8.5 ft to 9.5 ft and 1,568 vehicles for lane widths of 13 ft to 15.5 ft. The study assumed that all the adjustment factors were constant while varying only the lane width adjustment factor. The statistical analyses were conducted at 5% level of significance. The results showed that the SFR values were influenced by lane widths. In particular, the following average saturation flow rate ranges for specific lane widths were obtained at 5% level of significance: 1,736 – 1,752 pc/h/ln for 9.5 ft lanes; 1,815 – 1,830 pc/h/ln for 11 to 12-ft lanes; and 1,898 – 1,913pc/h/ln for lane widths of 13 ft or greater. A revision of the HCM lane with an adjustment factor of 12 ft lane was recommended.

The literature suggests that driver behavior also influences the value of the ideal saturation flow rate at intersections. Bonneson et al. [3] deduced from their study that unsteady flow in otherwise high-volume conditions could reflect the presence of aggressive drivers. Drivers achieve this by accepting relatively short headways during queue discharge. Dunlap [4] also proved that ideal SFRs are higher due to the presence of more aggressive drivers. Long [2] developed a driver-behavior model which offers evidence that the default SFR is not likely constant in many situations, especially when a significant number of aggressive drivers are in the traffic stream.

In summary, the literature showed a wide variation in base SFR values which are due to several factors, including intersection location, aggressive drivers, lane widths and jurisdiction, among others. Therefore, the casual use of the default SFR of HCM's base SFR in the conduct of LOS analyses, especially for operational purposes, could skew the results and impair some traffic safety, operations and engineering decisions. Therefore, there is the need to determine the local base SFR for each type of lane group in the District by first determining the prevailing SFR.

5 Research Methodology

5.1 Selected Sites for SFR Data Collection

5.1.1 Through Lane Group (T)

The research team collaborated with DDOT in identifying 60 signalized intersections for this study. They were selected based on their location in 6 zones previously defined by DDOT. Figure 3 shows the locations of the selected intersections by zones on the District map. Zone 5 represents the CBD of the District of Columbia.

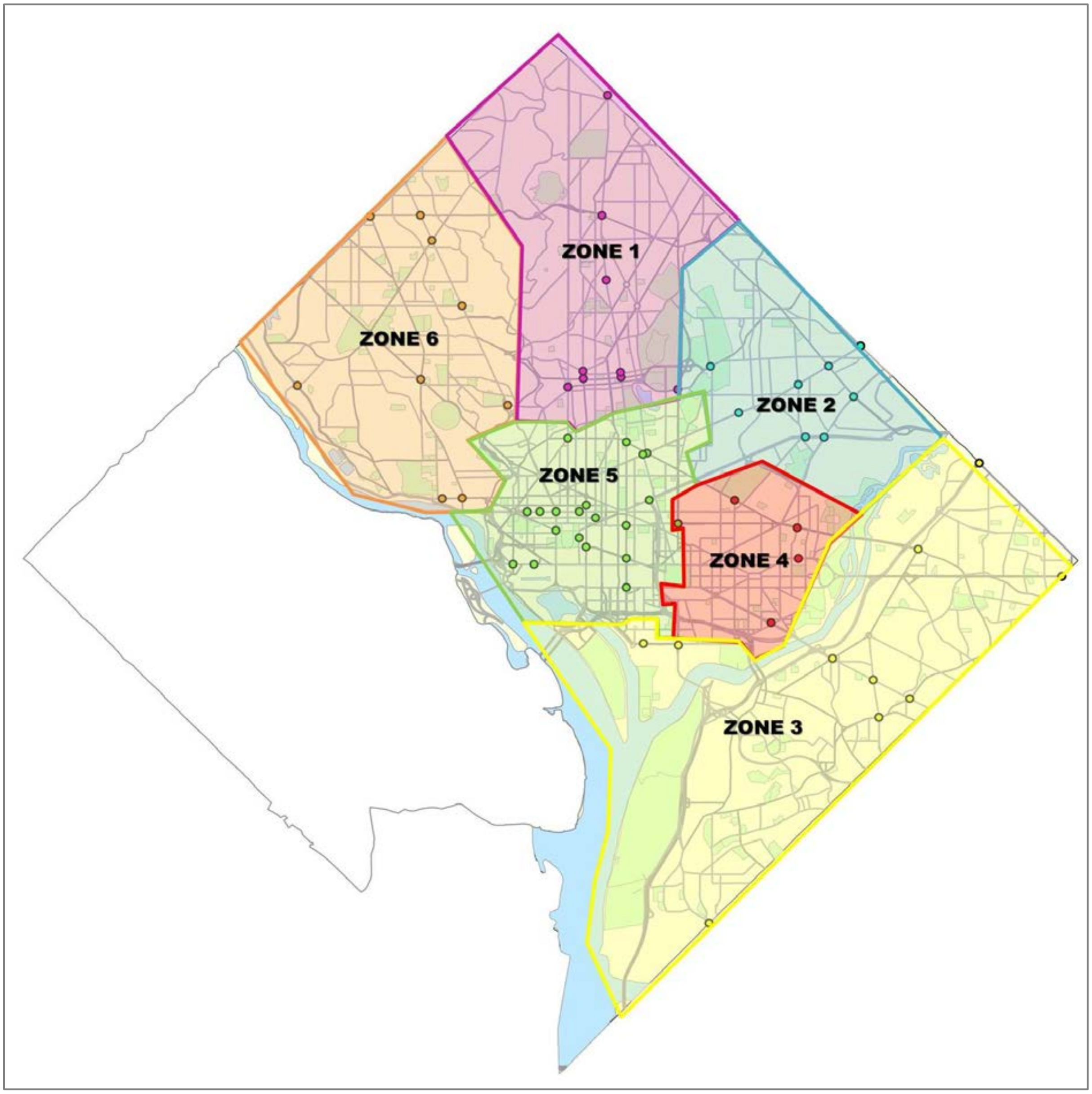
The remaining zones (1-4 and 6; or radial areas) feed into Zone 5. These intersections formed the basis for determining the prevailing SFR for the peak periods that are usually stipulated in requests for LOS analyses. The selected intersections also covered various types of intersections and lane groups. The list of the intersections is presented in Appendix 1.

Zone 1: The intersections in Zone 1 are primarily located in the northwest quadrant of the District. The zone is composed of residential areas with some commercial and education land uses. Georgia Avenue, which is located in this zone, is a major northbound and southbound arterial that connects Silver Spring, Maryland to the CBD with three lanes in each direction. There are major institutions along Georgia Avenue, including Howard University, Water Reed Army Medical Center, and Howard University Hospital.

Zone 2: The intersections in Zone 2 are located in the northeast quadrant of the District. Most of the intersections are located along Rhode Island Avenue and New York Avenue. Rhode Island Avenue is a major arterial, which connects the District to Prince George's County in Maryland. Rhode Island Avenue becomes US Route 1 in Maryland. New York Avenue is another major east-west arterial that runs parallel to Rhode Island Avenue and connects the District and Maryland commuters to the Baltimore-Washington Parkway, Interstate 395, and U.S. Route 50. This zone contains commercial retail shops (such as Home Depot, Target, and Costco) as well as residential areas.

Zone 3: The intersections in Zone 3 are located in the southeast quadrant of the District which is predominantly residential. The study focused on intersections on East Capitol Street and South Capitol Street. South Capitol Street is a major arterial that serves the southeast and southwest quadrants of the District and provides access to Maryland via Indian Highway (Maryland Route 210). East Capitol Street is another important arterial that serves the northeast and southeast quadrants of the District. This arterial becomes Maryland State Highway 214 (Central Avenue) in Maryland.

Figure 3: Map of Selected Intersections by Zones in the District of Columbia



Zone 4: The intersections in this zone are located in the eastern part of the District. The majority of the intersections in this zone serve several businesses, some of the Federal offices, and residential neighborhoods. Pennsylvania Avenue is one of the major arterials in this zone which provides access to the White House and the United States Capitol. This arterial is used by commuters from Maryland and Virginia to the District.

Zone 5: This zone represents the CBD of the District or the downtown area. It is the destination for most commuters since it has several businesses, Federal government offices, tourist attractions and several commercial activities.

***Zone 6*:** The intersections in Zone 6 are also located in the northwest quadrant of the District. Two of the major arterials in this zone are Connecticut Avenue and Wisconsin Avenue. These arterials serve businesses and institutions in the District and provide access to Montgomery County in Maryland. This zone serves the National Zoo, the University of the District of Columbia and several businesses and offices.

5.1.2 Shared Right and Through Lane Group (RT)

In collaboration with DDOT, 15 intersections were selected for the shared right and through lane group. These intersections were selected based on the availability of traffic volumes and queue lengths. The list of the locations is presented in Table 1.

Table 1: Selected Intersections for Shared Right and Through Lane Group

#	Location	Zone
1	Rhode Island Avenue & Eastern Avenue NE	2
2	New York Avenue & Bladensburg Road NE	2
3	South Dakota Avenue & Bladensburg Road NE	2
4	Pennsylvania Avenue & Branch Avenue SE	3
5	Alabama Avenue & Branch Avenue SE	3
6	17th Street & Benning Road NE	4
7	4th Street & New York Avenue NW	5
8	Southern Avenue SE & Wheeler Avenue SE	3
9	Benning Road & Minnesota Avenue NE	3
10	Wisconsin Avenue & Western Avenue NW	6
11	MacArthur Boulevard & Arizona Avenue NW	6
12	Pennsylvania Avenue & Alabama Avenue SE	3
13	Connecticut Avenue & Nebraska Avenue NW	6
14	Michigan Avenue & North Capitol Street NW	1
15	Connecticut Avenue & Military Road NW	6

5.1.3 Shared Left and Through Lane Group (LT)

Seven (7) intersections were selected for the shared left and through lane group. These locations were selected based on the signal phase sequence and the operation of the left turn movement. Only lead protected-permitted LT movements were considered. The list of intersections selected for this lane group is presented in Table 2.

Table 2: Selected Intersections for Shared Left and Through Lane Group

#	Location	Zone
1	Connecticut Avenue & Nebraska Avenue NW	6
2	Florida Avenue & 4th Street NE	4
3	Georgia Avenue & Eastern Avenue NW	1
4	Nebraska Avenue & New Mexico Avenue NW	6
5	14th Street NW & U Street NW	5
6	Connecticut Avenue & Porter Street NW	6
7	Western Avenue & River Road NW	6

5.1.4 Exclusive Left-turn Lane Group (L)

Four (4) locations were selected for the exclusive left-turn lane group. These locations were also selected based on the lead signal phase sequence and the protected-permitted operation mode of the turn movement. The intersections selected for the exclusive Left-turn lane group are presented in Table 3.

Table 3: Selected Intersections for Exclusive Left Lane Group

#	Location	Zone
1	17th Street & Benning Road NE	4
2	Michigan Avenue & North Capitol Street NE	1
3	Pennsylvania Avenue & Branch Avenue SE	3
4	Nebraska Avenue & Military Road NW	6

Figure 4 presents the locations for the RT, LT, and L group lanes in the District of Columbia.

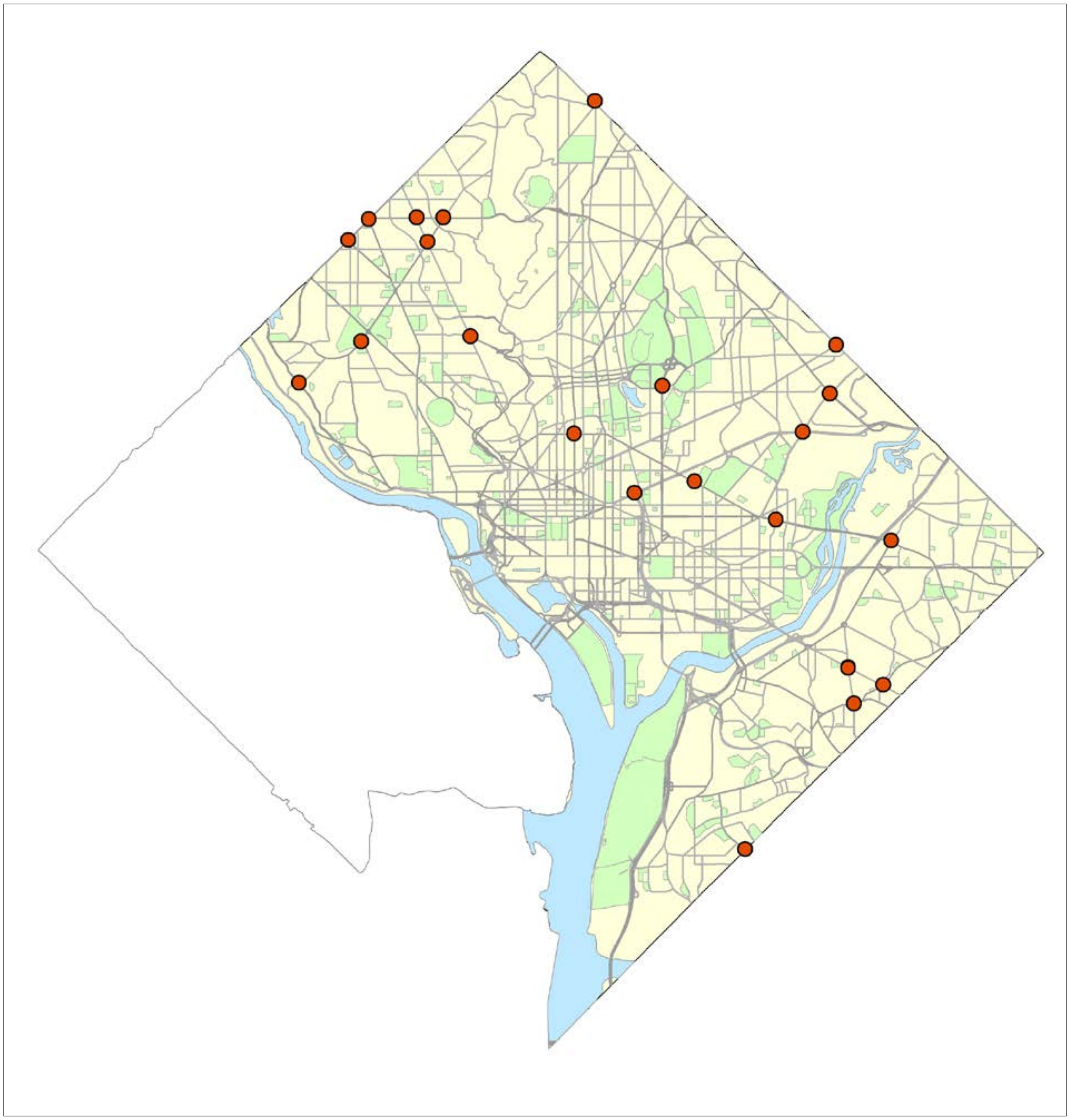
5.2 Data Collection

The research team conducted vehicle discharge headway observations for T, RT, LT, and L lane groups at the 67 intersections during the morning (7:30 AM to 10:30 AM) and afternoon (3:30 PM to 6:30 PM) peak hours on weekdays from Monday to Friday. The field data required determining the average headways based on which the prevailing SFRs for each lane group was computed using the procedures described in the 2010 HCM. A sample form of the actual data collected form is provided in Appendix 2. The data collection process started at the beginning of the green indication for the T and RT lane groups, while for the LT and L lane groups, it started at the beginning of the green ball and the green left turn arrow. For each lane group, the lane observed to have the longest queue was selected for observation. Using a stopwatch, the time (t_4) was recorded when the rear axle of the fourth vehicle crossed the stop bar of the approach. The time (t_n) was also recorded when the n^{th} observed vehicle in the queue at the beginning of green light crossed the stop bar. The total number (N) of vehicles stopped in the queue at the beginning of the green was also recorded. Based on the HCM's recommendation, a minimum of 15 cycles were observed to achieve a representative statistical sample. At least eight vehicles were observed in a queue before the data was recorded, otherwise, the data for that cycle was ignored.

The average headway, h, was then computed by

$$\bar{h} = \frac{t_n - t_4}{N - 4}$$

Figure 4: Selected locations for the RT, LT, and L group lanes



5.3 Data Analysis

When measured in the field, prevailing SFR have units of vehicles per hour per lane. This can be computed using the following formula:

$$s = 3600/h$$

where
s = saturation flow rate (vphpl)
h = average time headway (sec/veh)

The following descriptive statistics were computed for the lane groups for the morning and afternoon peak periods:

- Average headway
- Mean SFR
- Standard deviation (of the SFR)
- 95% confidence interval (of the SFR)

6 Results

6.1 Average Headways

Table 4 presents the summary of the mean headways for each lane group. These headway values were used to calculate the prevailing SFR.

Table 4: Summary of Mean Headways by Lane Group

Lane Groups	Mean Headway (sec)	
	AM	PM
Through	2.3	2.4
Right /Through	2.1	2.5
Left /Through	3.0	2.5
Left	2.4	2.6

6.2 Through Lane Group

The summary of the descriptive statistics for the prevailing SFR by zone for through lane is presented in Table 5. From the table, the highest mean prevailing SFR was determined to be 1,692 vphpl for the intersections in Zone 2, while the lowest was 1,523 vphpl in Zone 5 during the AM peak hour. The highest and lowest values of the mean prevailing SFRs in the PM peak hours were determined to be 1,613 and 1,480 vphpl in Zones 3 and 5 respectively. For the 60 intersections, the mean prevailing SFR for both AM and PM peak periods were 1,577 and 1,542 vphpl respectively, corresponding to an overall mean prevailing SFR of 1,559 vphpl for all the intersections. At a 95% confidence interval, this overall mean prevailing SFR falls between 1,363 and 1,755 vphpl.

Table 5: Summary of Mean Prevailing SFR (vphpl) by Zones for Through Lane Movement

Zones	AM			PM			Overall Mean
	Mean	STDEV	95% C.I.*	Mean	STDEV	95% C.I.*	
1	1,570	140.6	1,480-1,660	1,565	314.8	1,359-1,772	1,567
2	1,692	141.7	1,594-1,790	1,558	91.6	1,495-1,621	1,625
3	1,612	153.6	1,517-1,707	1,613	203.3	1,487-1,739	1,612
4	1,664	270.1	1,399-1,929	1,545	260.4	1,290-1,800	1,605
5	1,523	193.8	1,425-1,621	1,480	222.6	1,363-1,597	1,501
6	1,524	83.2	1,469-1,579	1,563	209.8	1,426-1,700	1,544

**C.I. = Confidence Interval*

6.3 RT, LT, and L Lane groups

Table 6 presents the summary of the average prevailing SFR for the RT, T, and L lane groups. From the table, the LT lane group had the highest prevailing SFR of 1,544 and 1,588 vphpl for the morning and afternoon peak hours, respectively. The average prevailing SFR for RT and L lane groups were generally higher during the morning peak hours than the afternoon peak hours. The overall mean prevailing SFRs were 1,461, 1,526, and 1,477 vphpl for the RT, LT, and L lane groups respectively.

Table 6: Summary of Mean Prevailing SFR by Lane Group

Lane Group	AM			PM			Overall Mean
	Mean	STDEV	95% C.I.*	Mean	STDEV	95% C.I.*	
Right/Through	1,495	143.7	1,442-1,606	1,426	166.2	1,288-1,478	1,461
Left/Through	1,544	231.8	1,312-1,754	1,518	266.8	1,271-1,765	1,526
Exclusive Left	1,470	89.6	1,166-1,736	1,503	79.1	1,251-1,755	1,477

**C.I. = Confidence Interval*

6.4 Comparing Average Prevailing SFRs

Figure 5 presents the average prevailing SFRs by lane group in the morning peak hours. From the figure, the T lane group had the highest mean prevailing SFR of 1,577 vphpl, while the L lane group had the lowest (1,451 vphpl). Also, the LT lane group recorded a mean prevailing SFR of 1,533 vphpl.

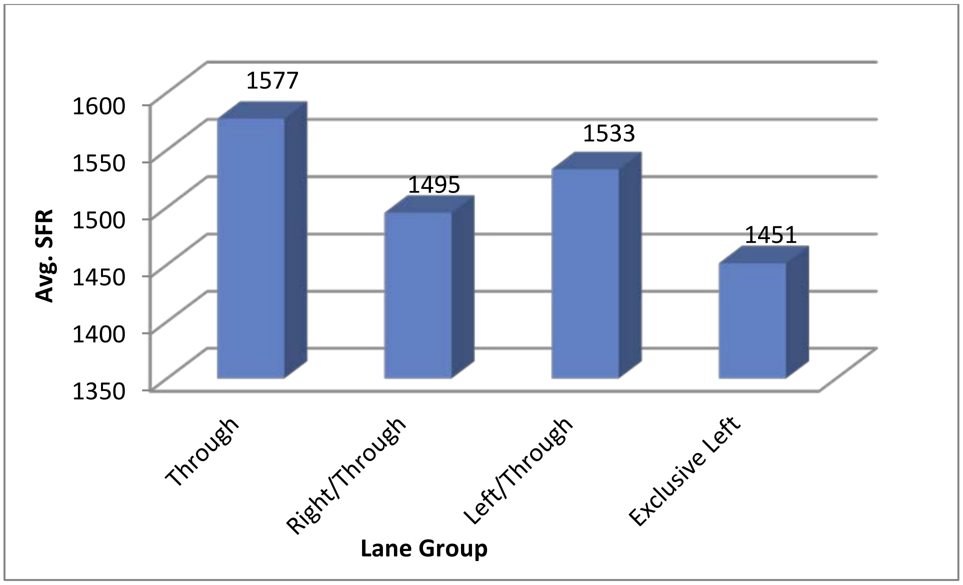


Figure 5: Mean prevailing SFR (vphpl) by lane groups during the AM peak hour

The mean prevailing SFRs by lane groups during the afternoon period are presented in Figure 6. It can be observed from the figure that the T lane group recorded the highest mean prevailing SFR of 1,542 vphpl, followed by the LT lane group (1,518 vphpl). Again, the RT lane group had the lowest mean prevailing SFR of 1,426 vphpl followed by the L lane group with 1,503 vphpl.

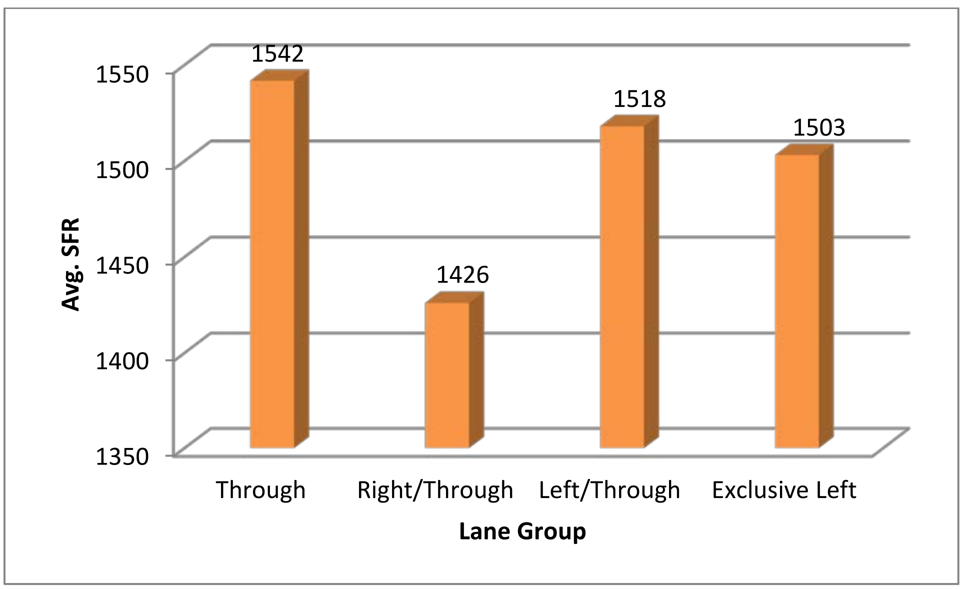


Figure 6: Mean prevailing SFR by lane groups during the PM peak hour

7 Discussion of Results

According to the 2010 HCM, determining the prevailing SFR for lane groups is the first step in the computation of a local base SFR for a city. A local base SFR is used to accurately determine the existing LOS and control delay of signalized intersections.

From the results, the highest mean prevailing SFR for the T lane group was determined to be approximately 1,692 vphpl during the PM peak hour, while the lowest was 1,523 vphpl during the AM peak hour. The highest and lowest values of the mean prevailing SFRs in the PM peak hour were determined to be 1,613 and 1,480 vphpl, respectively. For the 60 locations observed for the T lane group, the overall mean SFR was approximately 1,560 vphpl, which falls between 1,363 vphpl, and 1,755 vphpl at 95% confidence interval.

Also, the through lane group had the highest prevailing SFR of 1,577 vphpl during the AM peak hour and 1,588 vphpl during the PM peak hour. The mean prevailing SFRs were generally higher during the A.M peak hour for all the lane groups with the exception of the L lane group, which had a higher prevailing SFR during the afternoon peak hour.

8 Recommendations

Based on the outcome of this study, the local base SFR for signalized intersections can be determined following the process prescribed in the HCM. The next step will be to determine adjusted SFRs for the lane groups used in this study. Using the average prevailing SFR for the lane groups determined from this study, the local base SFR can then be computed using the following formula:

$$S_{o,local} = 1900 \left[\frac{\sum_{i=1}^{m} S_{prevailing,i}}{\sum_{i=1}^{m} S_i} \right]$$

where

$S_{o,local}$= local base saturation flow rate (pc/h/ln)

$S_{prevailing,i}$ = prevailing SFR for lane group i (veh/h/ln)

S_i= adjusted SFR for lane group i (veh/hr/ln) and

m= number of lane groups

9 References

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7. Potts I.B., Bauer, K.M., Harwood, D.W. and Gilmore, D.K. (2007), Relationship of Lane Width to Saturation Flow Rate on Urban and Suburban Signalized Intersection Approaches; Journal of the Transportation Research Board, No. 2027, pp.45-51.

APPENDIX 1

LIST OF INTERSECTIONS BY ZONE

(for Through Lane Group)

Selected Sites for SFR study

Zone 1 – North Capitol (9)

Georgia Ave & Missouri Ave NW
Georgia Ave & Irving St NW
16th St, Harvard St & Mt Pleasant NW
Georgia Ave & Eastern Ave NW
14th St & Park Rd NW
Georgia Ave & Kenyon St NW
Georgia Ave & Decatur St NW
14th St & Irving St NW
Michigan Ave & North Capitol St NW

Zone 2 – Northeast (8)

New York Ave & Bladensburg Rd NE
Rhode Island Ave & S Dakota Ave NE
Michigan Ave & Harewood Rd NE
South Dakota Ave & Bladensburg Rd NE
Rhode Island Ave & 18th St NE
Rhode Island Ave & Eastern Ave NE
New York Ave & Montana Ave NE
Rhode Island Ave & Reed St NE

Zone 3 – Southeast/Southwest (10)

S. Capitol St & M St
Kenilworth Ave & Eastern Ave NE
South Capitol & Southern Ave
Benning Rd & Minnesota Ave NE
E. Capitol St & Southern Ave
Pennsylvania Ave & Branch Ave SE
Pennsylvania Ave & Minnesota Ave SE
Alabama Ave & Branch Ave SE
Pennsylvania Ave & Alabama Ave SE
4th St & M St SW

Zone 4 - East Capitol (4)

17th St & Benning Rd NE
Pennsylvania Ave & Potomac Ave SE
Florida Ave & 8th NE
C street & 18th Street NE

Zone 5 – Downtown (20)

Connecticut Ave, K St, & 17th St NW
7th St & Pennsylvania Ave NW
4th St & New York Ave NW
16th St & U St NW
7th St & Independence Ave SW
N Capitol St & H St
Florida Ave & Rhode Island Ave NW
23rd St & Constitution St NW
20th St & Constitution Ave NW
14th Street & Pennsylvania Ave NW
19th St & K St NW
17th St & Pennsylvania Ave NW
15th, K St & Vermont Ave NW
15th St, G St, Pennsylvania Ave & New York Ave NW
21st St & K Street NW
13th St & I St NW
Rhode Island Ave & New Jersey Ave NW
Florida & Georgia Ave NW
7th & H Street NW
14th St & L St NW

Zone 6 – Northwest (9)

34 St & M St NW
Wisconsin Ave & M St NW
Wisconsin Ave & Western Ave NW
Wisconsin Ave & Massachusetts Ave NW
Connecticut Ave & Military Rd NW
Connecticut Ave & Nebraska Ave NW
Connecticut Ave & Calvert St NW
Connecticut Ave & Van Ness St NW
Macarthur Blvd & Arizona Ave NW

APPENDIX 2

SAMPLE SATURATION FLOW RATE DATA COLLECTION FORM

Sample Field Data Collection Form

HUTRC

Saturation Flow Rate Data Collection Sheet

PROTECTED PERMITTED -LEFT TURN

Intersection : Pennsylvania Ave and Branch Ave SE **Lane :** 2
Approach : WB **Technician :** Soni
Weather : Cloudy **Time :** 7.48am - 8.36am
Pav. Condition : Wet **Date :** 12/05/14

Cycle	T_4	T_n	# Vehicles
1	8.33	22.13	10
2	14.45	28.35	10
3	11.59	22.54	9
4	11.58	20.80	9
5	11.96	20.70	8
6	16.61	22.10	8
7	18.58	30.30	10
8	8.49	26.48	9
9	9.80	19.60	8
10	12.34	21.10	9
11	10.96	21.21	10
12	9.43	16.73	8
13	9.80	18.20	9
14	10.11	22.73	10
15	7.49	21.16	9
16	10.26	18.28	8
17	8.31	18.23	8
18			
19			
20			

T_4 = Time(in seconds) the last vehicle's rear axle crossed a stop bar from a standing queue when the signal indication turned green.

T_n = Time (in seconds) the fourth vehicle's rear axle crossed a stop bar from a standing queue when the signal indication turned green.

* Minimum of 8 vehicles at each queue.

* Minimum of 15 cycles to be recorded.

APPENDIX 3

Descriptive Statistics by Lane Group

THROUGH LANE GROUP

Descriptive Statistics for Zone 1

North Capitol	Average SFR AM	Average SFR PM
Georgia Ave. & Missouri Ave., NW	1564.9	1558.0
Georgia Ave. & Irving St., NW	1534.0	1601.2
16th St., Harvard St. & Mt. Pleasant St., NW	1597.8	1456.3
Georgia Ave. & Eastern Ave., NW	1552.3	1471.0
14th St. & Park Rd., NW	1544.9	1234.5
Georgia Ave. & Kenyon St., NW	1664.7	2328.8
Georgia Ave. & Decatur St., NW	1809.3	1636.6
14th St. & Irving St., NW	1272.3	1305.5
Michigan Ave. & North Capitol St., NW	1586.1	1489.3
Mean	***1569.6***	***1564.6***
Median	***1564.9***	***1489.4***
Standard Deviation	***140.6***	***314.8***
95% Confidence Interval	***1477.8 – 1661.5***	***1358.9 – 1770.3***

Descriptive Statistics for Zone 2

North East	Average SFR AM	Average SFR PM
New York Ave. & Bladensburg Rd., NE	1663.6	1547.1
Rhode Island Ave. & S. Dakota Ave., NE	1598.6	1547.1
Michigan Ave. & Harewood Rd., NE	1956.1	1586.4
South Dakota Ave. & Bladensburg Rd., NE	1773.7	1669.1
Rhode Island Ave. & 18th St., NE	1641.7	1546.9
Rhode Island Ave. & Eastern Ave., NE	1739.0	1685.0
New York Ave. & Montana Ave., NE	1693.2	1418.8
Rhode Island Ave. & Reed St., NE	1468.5	1459.4
Mean	***1691.8***	***1557.5***
Median	***1678.4***	***1547.1***
Standard Deviation	***141.7***	***91.6***
95% Confidence Interval	***1593.6 – 1790***	***1494 – 1621***

Descriptive Statistics for Zone 3

Southeast/ Southwest	Average SFR AM	Average SFR PM
South Capitol Street & M Street, SE	1461.0	1601.9
Kenilworth Avenue & Eastern Avenue, NE	1703.8	1502.6
South Capitol Street & Southern Avenue, SE	1793.9	1428.6
Benning Road. & Minnesota Avenue, NE	1467.4	1511.3
E. Capitol Street & Southern Avenue, SE	1812.1	2046.9
Pennsylvania Avenue & Branch Avenue, SE	1625.3	1724.6
Pennsylvania Avenue & Minnesota Avenue SE	1508.3	1848.5
Alabama Avenue & Branch Avenue, SE	1796.7	1484.2
Pennsylvania Avenue & Alabama Avenue, SE	1430.5	1565.3
4th Street & M Street, SW	1516.7	1412.5
Mean	***1611.6***	***1612.7***
Median	***1571.0***	***1538.3***
Standard Deviation	***153.6***	***203.3***
95% Confidence Interval	***1516.4 – 1706.8***	***1486.7 – 1738.7***

Descriptive Statistics for Zone 4

East Capitol	Average SFR AM	Average SFR PM
17th St & Benning Rd, NE	2034.0	1532.9
Pennsylvania Ave. & Potomac Ave SE	1501.9	1552.4
Florida Ave. & 8th St. NE	1429.8	1229.3
C Street & 18th Street NE	1691.6	1867.0
Mean	***1664.3***	***1545.4***
Median	***1596.7***	***1542.6***
Standard Deviation	***270.1***	***260.4***
95% Confidence Interval	***1399.7 - 1927***	***1290.2 – 1800.6***

Descriptive Statistics for Zone 5

Downtown	Average SFR AM	Average SFR PM
Connecticut Avenue/ K Street/ 17th Street, NW	1525.4	1692.0
7th Street & Pennsylvania Avenue, NW	1590.1	1480.8
4th Street & New York Avenue, NW	1203.7	1200.5
16th Street & U Street, NW	1557.1	1720.5
7th Street & Independence Avenue, SW	1699.0	1495.4
N. Capitol Street & H Stret, NW	1628.7	1712.7
Florida Avenue & Rhode Island Avenue, NW	1638.6	1443.2
23rd Road & Constitution Street, NW	1465.5	1538.2
20th Street. & Constitution Avenue, NW	1613.0	1841.7
14th Street & Pennsylvania Avenue, NW	1670.6	1226.9
19th Street. & K Street, NW	1559.0	1106.8
17th Street & Pennsylvania Avenue, NW	1347.4	1227.1
15th ,K Street. & Vermont Avenue, NW	1757.7	1603.0
15th Street, G Street ,Penn. Ave & N.Y. Ave NW	1777.9	1688.1
21st Street. & K Street, NW	1201.4	1371.1
13th Street & I Street, NW	1429.7	1528.6
Rhode Island Avenue & New Jersey Avenue, NW	1732.7	1740.5
Florida Avenue & Georgia Avenue, NW	1360.2	1157.7
7th Street & H Street, NW	1591.3	1563.1
14th Street & L Street, NW	1100.9	1252.2
Mean	***1522.5***	***1479.5***
Median	***1574.5***	***1512.0***
Standard Deviation	***193.8***	***222.6***
95% Confidence Interval	***1437.5 – 1607.5***	***1381.9 – 1571.1***

Descriptive Statistics for Zone 6

Northwest	Average SFR AM	Average SFR PM
34th Street & M St., NW	1425.9	1348.6
Wisconsin Avenue & M St., NW	1617.6	1616.3
Wisconsin Ave. & Western Ave., NW	1494.3	1403.0
Wisconsin. Ave. & Massachusetts. Ave., NW	1456.5	1652.7
Connecticut Ave.& Military Rd., NW	1529.9	2038.1
Connecticut Ave.& Nebraska Ave., NW	1572.1	1454.5
Connecticut Ave. & Calvert St., NW	1663.3	1635.7
Connecticut Ave. & Van Ness St., NW	1532.6	1507.7
Macarthur Blvd. & Arizona Ave., NW	1425.0	1408.7
Mean	***1524.1***	***1562.8***
Median	***1529.9***	***1507.7***
Standard Deviation	***83.2***	***209.8***
95% Confidence Interval	***1469.7 – 1578.5***	***1425.8 – 1699.9***

Descriptive Analyses for all the Intersections

Intersections	Overall AM	Overall PM
Mean	***1576.7***	***1541.7***
Median	***1579.1***	***1535.5***
Standard Deviation	***171.3***	***220.1***
Confidence interval	***1533.3 – 1620***	***1486 – 1597.4***

SHARED RIGHT AND THROUGH LANE GROUP

Intersection	Average SFR AM	Average SFR PM
Rhode Island Ave. and Eastern Ave., NE	1568.0	1343.0
New York Ave. and Bladensburg Rd., NE	1425.0	1748.0
South Dakota Ave. and Bladensburg Rd., NE	1484.0	1567.0
Pennsylvania Ave. and Branch Ave., SE	1640.0	1579.0
Alabama Ave. and Branch Ave., SE	1674.0	1473.0
17th St. and Benning Rd., NE	1453.0	1274.0
4th St. and New York Ave., NW	1117.0	1094.0
Southern Ave. and Wheeler Rd., SW	1454.0	1362.0
Benning Rd. and Minnesota Ave., NE	1648.0	1306.0
Wisconsin Ave. and Western Ave., NW	1276.0	1255.0
McArthur Boulevard and Arizona Ave., NW	1425.0	1351.0
Pennsylvania Ave. and Alabama Ave., SE	1581.0	1508.0
Connecticut Ave. and Nebraska Ave., NW	1554.0	1480.0
Michigan Ave. and North Capitol St., NW	1604.0	1671.0
Connecticut Ave. and Military Rd., NW	1524.0	1383.0
Mean	**1495.0**	**1426.0**
Median	**1524.0**	**1383.0**
Standard Deviation	**143.7**	**166.2**
95% Confidence Interval	**1442 - 1606**	**1288 - 1478**

SHARED LEFT AND THROUGH LANE GROUP

Intersection	Average SFR AM	Average SFR PM
Connecticut Ave and Nebraska Ave NW	1744	1464
Florida Ave and 4th St NE	1404	1178
Georgia Ave and Eastern Ave NW	1501	1571
Nebraska Ave and New Mexico	1336	1454
14th St and U St NW	1230	1257
Connecticut Ave and Porter St NW	1604	1774
Western Ave and River Rd	1915	1928
Mean	**1533**	**1518**
Median	**1501**	**1464**
Standard Deviation	**239.4**	**266.8**
95% Confidence Interval	**1312-1754**	**1271-1765**

EXCLUSIVE LEFT-TURN LANE GROUP

Intersection	Average SFR AM	Average SFR PM
17th St and Benning Rd NE	1452	1601
Michigan Ave and North Capitol NE	1239	1267
Pennsylvania Ave and Branch Ave SE	1677	1587
Nebraska Ave and Military Rd	1435	1555
Mean	**1451**	**1503**
Median	**1444**	**1571**
Standard Deviation	**89.6**	**79.1**
95% Confidence Interval	**1166-1736**	**1251-1755**