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Exploring Strategies to Improve Mobility and Safety on Roadway Segments in Urban Areas

Stephen Arhin
Howard University; Mineta Consortium for Transportation Mobility

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Stephen Arhin, Ph.D.

MINETA TRANSPORTATION INSTITUTE

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Mineta Consortium for Transportation Mobility

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EXPLORING STRATEGIES TO IMPROVE MOBILITY AND SAFETY ON ROADWAY SEGMENTS IN URBAN AREAS

Stephen Arhin, Ph.D.

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16. Abstract

Several strategies have been proposed and developed to alleviate the congestion and throughput problem usually experienced in urban areas. These strategies include the use of Intelligent Transportation Systems, signal re-timing and signal coordination, among others. In urban areas, there are often combinations of signalized and un-signalized intersections on corridors that may impact throughput and mobility. This research investigated driver compliance rate (CR) with STOP-signs at All-Way STOP Control (AWSC) intersections that are in close proximity to upstream or downstream signalized intersections. Also, strategies to improve mobility and throughput on segments in an urban area were explored via modeling and simulation.

Thirty isolated segments with combinations of signalized and un-signalized intersections in the District of Columbia were selected for the study. Field data (traffic volumes, signal timing, lane configurations, etc.) were collected at each intersection of the segments. Driver compliance with STOP-signs at AWSC intersections within the segments was also observed. In all, 13,956 observations were made at 57 AWSC intersections. The segments were then modelled in the software program, and two scenarios were simulated. The "before" scenario simulated the existing conditions on the segments. In the "after" scenario, the AWSC intersections in each segment were signalized (and optimized), while maintaining the same conditions at the signalized intersections. Control delay and average travel speed were the measures of effectiveness (MOEs) that were used to assess the performance of the segments in both scenarios.

The results of a regression analysis showed a positive relationship between CR and the distance between the existing AWSC and signalized intersections. A nonlinear regression model developed indicates that, to achieve a minimum compliance rate of 95%, a minimum distance of approximately 1,298 ft. between the intersections is required. Also, a test of comparison of means of the segments' MOEs in the "before" and "after" scenarios showed significant improvements in the "after" scenarios. Statistically significant reductions in control delays on the segments were reported, while the average travel speed of vehicles significantly increased. The study revealed that even though some un-signalized intersections may not meet the MUTCD warrants for signalization, signalizing and coordinating them with existing signalized intersections will improve mobility and throughput.

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EXECUTIVE SUMMARY

Congestion is a critical problem in dense urban areas in the United States. In 2016, Los Angeles, California was ranked the most congested city in the United States with 104 hours of congestion during that year. Most roadway networks in urban areas consist of combinations of signalized and unsignalized intersections for managing safety, throughput and mobility. The Manual on Uniform Traffic Control Devices (MUTCD) has prescribed warrants for signalizing intersections. However, on some corridors where unsignalized intersections do not meet the MUTCD warrants, their adverse effect on mobility is compounded.

This research investigated driver compliance rate (CR) with STOP-signs at All-Way STOP Control (AWSC) intersections that are in close proximity to upstream or downstream signalized intersections and explored the existence of a relationship between CR and the distance between the two successive intersections in the traffic stream. In addition, strategies to improve mobility and throughput on segments in an urban area were explored via modeling and simulation.

Thirty isolated segments with combinations of signalized and unsignalized intersections in the District of Columbia were selected for the study. Field data (traffic volumes, signal timing, lane configurations, etc.) were collected at each intersection of the segments. Driver compliance with STOP-signs at AWSC intersections within the segments were also observed. In all, 13,956 observations were made at 57 AWSC intersections. The segments were then modelled in the software program, and two scenarios were simulated. The “before” scenario simulated the existing conditions on the segments. In the “after” scenario, the AWSC intersections in each segment were signalized (and optimized), while maintaining the same conditions at the signalized intersections. Control delay and average travel speed were the measures of effectiveness (MOEs) that were used to assess the performance of the segments in both scenarios.

The study showed that lower CRs were observed at AWSC intersections that were in closer proximity to the signalized intersections. Thus, the shorter the distance between the existing AWSC to signalized intersections, the lower was the CR (or the higher was the violation rate). The results of a regression analysis showed a positive relationship between CR and the distance. The regression model developed indicates that, to achieve a minimum compliance rate of 95%, a minimum distance of approximately 1,298 ft. between the intersections is required. Also, a test of comparison means of the segments’ MOEs in the “before” and “after” scenarios showed significant improvements in the “after” scenarios. Statistically significant reductions in control delays on the segments were reported, while the average travel speed of vehicles significantly increased. The research showed that even though some unsignalized intersections may not meet the MUTCD warrants for signalization, signalizing and coordinating them with existing signalized intersections improves mobility and throughput.

I. INTRODUCTION

Several cities across the United States are rethinking their strategies to improve mobility. Urban population is increasing considerably, and roadways are reaching their capacity as travel times increase, and congestion rises. According to the United Nations, in 2016 approximately 54.5% of the population lived in urban settlements, and this number is expected to increase to 60% by 2030. Urbanization statistics indicate that, sooner rather than later, urban infrastructure will be overburdened, and the quality of life of urban residents will decrease dramatically.

In the United States, congestion has become a critical problem in dense urban areas. In 2016, Los Angeles, California was ranked the most congested city in the United States with 104 hours of congestion during that year. Meanwhile, commuters in Washington, DC spent 60 hours in traffic, costing the region's economy approximately 3 billion dollars in the same year. It is therefore critical for local transportation agencies to reduce congestion and improve mobility. Both federal and local governments recognize the limitation in expanding the physical transportation infrastructure and have explored the different strategies that could be employed to improve throughput, thereby reducing congestion.

In urban areas, most roadway networks consist of combinations of signalized and unsignalized intersections that may affect throughput and mobility. The MUTCD has prescribed warrants for signalizing intersections. However, on some corridors where unsignalized intersections do not meet the MUTCD warrants, their effect on mobility on the corridor is compounded. Moreover, for unsignalized intersections in close proximity to the signalized intersections, compliance with the STOP sign is often violated. Drivers often violate STOP signs in order to travel through the next signalized intersection that may have the green interval.

This research explores the strategy, via modeling and simulation, where such intersections could be signalized and coordinated with existing signalized intersections to improve mobility along those corridors while eliminating driver violations of STOP signs. Thirty segments with combinations of signalized and unsignalized intersections were used in this study. Each segment consisted of at least two signalized intersections and one AWSC intersection where field data collection was conducted (traffic volumes, signal timing, lane configurations, etc.). STOP sign compliance was observed in the "before" scenario, after which segments were modeled using Synchro 9™ software program, based on which a strategy for mobility improvement was explored. The MOEs evaluated were control delay and average travel speed.

The hypothesis that there is a relationship between STOP-sign compliance rate and the distance between each AWSC and signalized intersections (downstream or upstream) was also explored. The model could potentially be used to determine the optimal distance between a pair of AWSC and signalized intersections that may minimize driver noncompliance with STOP signs within segments.

II. RESEARCH OBJECTIVES

This research focused on roadway segments in the District of Columbia, which is a built-up urban area with unique street configurations that are often plagued with congestion, mobility and throughput issues. The following are the objectives of this study:

- To determine average driver CR at AWSC intersections near signalized intersections.
- To explore the existence of a relationship between CR and the distance between the unsignalized and signalized intersection. Such a relationship could be used to determine the optimal distance between the AWSC and signalized intersections that might help reduce noncompliance of STOP signs within the segments.
- To explore the viability of signalizing the unsignalized intersections to improve mobility and throughput on segments in an urban area via modeling and simulation.

III. LITERATURE REVIEW

Transportation mobility is defined as the movement of people and goods from one location to another.[1] Among the many factors that affect mobility and throughput, traffic congestion is the most critical. This is especially so in urban areas during morning and evening peak hours. The cost of traffic congestion in the United States was estimated to be $124 billion as of 2013. Specifically in metropolitan areas, it accounts for $87 billion dollars annually and is estimated to increase to $186 billion by 2030. The major contributors to these dollar values are the costs arising from the time wasted in traffic, excessive fuel consumption, and the degradation of the environment.[2]

Traffic congestion proliferates losses and results in negative impacts in many sectors of the urban lifestyle including harm to the environment and reduction in quality of life, productivity, and business success. In 2003, Weisbrod et al. studied the effect on economic costs as a result of urban traffic congestion.[3] The strategic empirical analysis investigated different characteristics of resulting business operations costs due to congestion in metropolitan areas. The study incorporated data collection and statistical analysis to examine different types of business activities and their correlation with costs of transporting products and commuting workers. Data on patterns of business locations, travel patterns and commuting trips was obtained from Chicago (1,669 zones) and Philadelphia (1,510 zones) metropolitan areas. Regression analysis was employed to establish coefficients (levels of business activities in selected zones) as functions of different factors including labor access, commuting and delivery charges.

The output obtained from the calibrated models for Chicago and Philadelphia produced uniform results in the field of industry differences in congestion costs, effect on travel pattern and economies of scale. There were significantly higher costs for areas with industries associated with extensive labor requirements and higher levels of truck shipping during congestion. There was no significant impact of congestion on the firms with lower-skilled labor and input requirements. The model predicted a six-and-a-half percent increase in business productivity when the effective labor market was doubled. The authors also investigated different hypothetical scenarios (six percent reduction in delays of truck delivery in downtown business district and central industrial area outside downtown, 10% reduction in worker commuting, and 50% reduction in commuting delays). The annual change in business costs after the analysis for truck deliveries ranged from $252-272 million for Chicago and $23-100 million for Philadelphia. The reduction of congestion for truck deliveries to downtown businesses resulted in increased profits since it allowed businesses to focus on service.

Economic benefit was also observed at the periphery of urban areas after reducing congestion region-wide, signifying the possibility of increase in business efficiency and a reduction in the need to disperse labor and delivery markets. Transportation demand has continued to increase over the past years.[4] In addition to the delays that residents in urban areas (e.g., Washington, DC) experience on a daily basis, congestion also affect other aspects of the environment such as air quality. According to the INRIX Global Traffic Scorecard,[5] Washington DC is the sixth most congested city in the U.S. and the 18th in the world. The report indicates that residents in the DC metropolitan area spend approximately

61 hours in traffic, which in turn costs each driver nearly $1,700 per year and costs the region's economy more than $2.9 billion.

The causes of traffic congestion are well documented, with high traffic volumes and frequent interruptions of traffic flow in the lead. The most common traffic flow interruptions originate at or near intersections. Ideally, it is recommended that the minimum spacing for intersections in urban areas be 0.5 miles.[6] In urban areas, however, intersections are much more closely spaced since there is a competing need for providing an adequately dense street network to allow road users to have several route options and to provide land access. Intersections in urban areas are either controlled or uncontrolled. When access to an intersection is regulated by traffic signals or regulatory signs, it said to be controlled, while it is uncontrolled when access is regulated by right-of-way rules. Controlled intersections are either signalized or unsignalized. Signalized intersections are controlled by signals while unsignalized intersections are controlled by either STOP signs or yield signs. The STOP signs are installed either on the minor roads only (Two-Way STOP control – TWSC) or on all approaches (AWSC).

In dense urban areas, most of the roadway networks consist of combinations of signalized and unsignalized intersections, which may affect throughput and mobility. The MUTCD has prescribed warrants for signalizing intersections. However, on some corridors where unsignalized intersections do not meet the MUTCD warrants for signalization, their effect on mobility is compounded. According to the MUTCD, Section 1A-09, the decision to use a particular traffic control device at a specified location should be made based on an engineering study or the application of an engineering judgment, both of which shall be performed by an engineer or by an individual working under the supervision of an engineer.[7] In 2015, a total of 48,923 vehicles were involved in fatal crashes in the United States. Out of the total, approximately 4.4% (2,157) of the fatal crashes occurred at STOP-controlled intersections, while 7.5% (3,672) of the crashes occurred at intersections controlled by traffic signals. On the other hand, intersections without any type of traffic control device recorded the highest number of fatal crashes (4,227).[8]

The Federal Highway Administration (FHWA) reported that since 2005, there has been a decline in the overall number of crashes that occur at or in close proximity to intersections.[9] Nevertheless, crashes at intersections are still a major concern for traffic authorities. Most of these crashes occur due to the failure of a driver to stop or yield the right-of-way.

STRATEGIES FOR IMPROVING MOBILITY ON CORRIDORS

Several strategies have been adopted to improve congestion mobility and safety on road corridors. These measures are aimed at minimizing delays at signalized intersections and on road segments. Some of these strategies are described in the following sections.

Actuated Signalized Controls

Actuated signals are traffic signals with the capability to respond to the presence of vehicles or pedestrians at intersections. Phase intervals are called and extended via the use of vehicle detectors. In such a system, traffic signal controllers are not only capable of varying the cycle length and green times in response to detector actuation, but can also alter the order and sequence of phases. This type of mobility improvement strategy has the advantage of reducing delay, being adaptable to short-term fluctuations in traffic flow and increasing highway capacity. On the other hand, actuated signalized controls can be rendered redundant if traffic demand pattern regularizes over time. In addition, the installation and maintenance cost are known to be three times that of pre-timed signals.[10]

Traffic Signal Coordination

Traffic signal coordination is a mechanism which allows a series of signals along a corridor to turn green based on synchronized timers, pre-assigned speeds to current traffic patterns, and congestion levels. This system aims at clearing the maximum number of vehicles through consecutive intersections at maximum safe speeds and minimal delays. This mechanism is known to be a cost-effective alternative for reducing travel delays.[11]

Signal Re-Timing

Signal re-timing optimizes the operations of signalized intersections by developing and implementing new signal-timing parameters. This has been proven to be an effective way of reducing delay time on corridors where traffic patterns are reasonably constant over time. The benefits of signal re-timing include fewer stops, reduced fuel consumption, and reduced delays along coordinated signalized corridors. The analysis of the results of signal re-timing performed on a section of New Hampshire Avenue, in Washington, DC, showed that delays were reduced by 13% and progression through the section improved.[12]

Reversible Traffic Lanes and One-Way Lanes

The direction of a lane on a two-way road can be reversed to increase the capacity of the peak direction. Thus, available lane capacity is temporarily obtained from the off-peak direction to reduce congestion. This strategy is effective in handling special event traffic, morning and evening peak commutes periods and construction and maintenance activities. These adjustments (managed by changeable message signs and/or arrow panels) occur at specified times of day, or when volume exceeds certain limits. The direction of the reversed lane at a particular time is indicated by variable message signs.[13]

Furthermore, a few measures have been proposed to improve mobility and throughput at unsignalized intersections. For unsignalized intersections in close proximity to or in between signalized intersections, the FHWA recommends the re-timing of adjacent signals to create more gaps in traffic for turning maneuvers at unsignalized intersections. The re-timing process could also require changing the phasing of the existing signal. The downside of this measure is that re-timing could reduce the level of service and progression on through streets. Automated real-time systems and innovative signs and markings to inform drivers of suitable gaps for turning or crossing maneuvers have also been proposed.[14]

Other Measures

Decreasing congestion and increasing mobility along corridors are both integral parts of an efficient transportation network for the DC region. Vehicle crashes, breakdowns, construction or other unpredictable events result in approximately half of the congestion in large urban areas. According to Staley (2012), improving arterial efficiency provides significant benefits for relatively small costs. Some strategies for improving efficiency include traffic signal optimization, Intelligent Transportation Systems (ITS) deployments and incident management.[15] Staley's study showed that traffic signal optimization in cities like London, Los Angeles and Beijing has improved travel time by up to 13%, and traffic signal coordination has greatly reduced delays along arterial roadways. In addition, some roadway segments may no longer be sufficient to carry volumes of traffic generated through urbanization. Hence, there may be a need to reconfigure existing traffic flow patterns or completely redesign intersections to serve new travel needs and patterns.

Traffic-signal-timing optimization, properly implemented, could significantly improve network performance by reducing delay, increasing network throughput, reducing number of stops, or increasing average travel speed in the network. Another effective method for congestion reduction is transportation supply management, which can be implemented in the form of optimal or near-optimal signal-timing parameters in a network (i.e., cycle length, phase plane, green splits, and offset optimization). It is a known fact that signal timing at one intersection can impact the state of other intersections. The majority of traffic-signal optimization methods use the concept of delay minimization, either alone or in combination with other factors. Delay minimization works well in undersaturated conditions where demand is less than the capacity and usually the queue dissipates before the green signal ends. The goal of improving mobility and reducing congestion for transportation systems within urban areas can also be tackled using ITS deployments. ITS can support a regional communications system that provides real-time travel conditions and emergency management information to transportation agencies, emergency response providers and the general public. In many large urban areas, congestion may result from incident-driven sources such as vehicle crashes, construction, or other unpredictable events. Using regional traffic management technology such as a Closed-Circuit Television (CCTV) to change traffic signal timings at intersections can significantly improve travel speeds.

PERFORMANCE INDICATORS FOR MOBILITY AND THROUGHPUT

In evaluating mobility and throughput on road networks, traffic engineers utilize certain performance indicators which are derived from traffic data such as traffic volumes, speeds and traffic control devices. These performance indicators include Level of Service (LOS), vehicular delays, queue lengths, travel times and headways.

Level of Service (LOS)

The LOS of intersections and urban streets describes their quality of service. At intersections, the LOS is evaluated based on the average control delay per vehicle for movements through the intersection. On urban streets, the LOS is defined as the mean speed of through traffic.

In a survey conducted by Sutaria and Haynes (1977), it was revealed that delay ranked first among other factors (such as traffic congestion, number of stops, difficulty in changing lane and number of buses) that influenced participants' perception of the quality of service of an intersection.[16] The 2016 Highway Capacity Manual prescribes six levels of services ranging from A to F based on the average vehicle delay (at intersections) and mean speed traffic (on urban streets). Tables 1 through 3 present the LOS criteria for unsignalized, signalized and urban streets, respectively.

Table 1. Level of Service Criteria for Unsignalized Intersections

Level of Service	Average Control Delay (sec/veh)
A	0 to 10
B	> 10 to 15
C	> 15 to 25
D	> 25 to 35
E	> 35 to 50
F	> 50

veh = vehicle.

Table 2. Level of Service Criteria for Signalized Intersections

Level of Service	Average Control Delay (sec/veh)
A	≤10
B	> 10 to 20
C	> 20 to 35
D	> 35 to 55
E	> 55 to 80
F	> 80

veh = vehicle.

Table 3. Level of Service Criteria for Urban Streets

Urban Street Class	Free-Flow Speed (mph)	Travel Speed Threshold (Lower Limit) by Level of Service (mph)				
		A	B	C	D	E
I	55	>47	>37	>28	>22	>17
	50	43	34	25	20	15
	45	38	30	23	18	14
II	45	38	30	23	18	14
	40	34	27	20	16	12
	35	30	23	18	14	11
III	35	30	23	18	14	11
	30	26	20	15	12	9
IV	35	30	23	18	14	11
	30	26	20	15	12	9
	25	21	17	13	10	8

mph = Miles per Hour.

Travel Time

Travel time is the total time spent traveling along a route between any two points of interest. It is usually obtained by either directly measuring this time on the field or using computer simulation models. Travel time comprises of running time (or time in which the mode of transport is in motion) and stopped delay time (or time in which the mode of transport is stopped).[17]

Headway

There are two types of headway: time headway and space headway. Time headway is the time difference between any two successive vehicles when they cross a given point. Space headway is the distance between corresponding points of two successive vehicles at any given time. The average of vehicle headways is the reciprocal of flow rate; hence vehicle headways represent microscopic measures of flows passing a point and the roadway capacity.[18,19]

Queue Lengths

Queue lengths at intersections are parameters used to estimate capacity. At signalized intersections, the most critical queue length is measured at the end of the red interval. While the average queue length gives an indication of the capacity of the intersection, the 95th percentile queue length is used to determine the length of turning lanes in intersection design.[20]

FACTORS INFLUENCING NONCOMPLIANCE AT UNSIGNALIZED INTERSECTIONS

Several studies have been conducted to determine the different factors that affect drivers' compliance with right-of-way rules at intersections. In 1977, Mounce concluded that traffic volumes on a major roadway had a strong negative relationship with the total violation rate. According to Mounce, as traffic volume increases, the total number of violations decreased. This was established by observing motorists' compliance at 66 unsignalized intersections in south central Texas, during which a total of 2,830 vehicles were observed. The variables considered in this study were major roadway volume, minor roadway sight distance, traffic conditions and intersection geometry.[21]

Mounce observed three levels of compliance: full compliance, partial violation and complete violation. A vehicle was considered to be fully compliant if it came to a complete stop at the STOP sign. A partial violation was defined as when a vehicle entered the intersection with a rolling stop at a speed of approximately five mph. A complete violation was when a vehicle didn't stop before entering the intersection with a speed of five mph or more. The compliance rate of each intersection was then calculated.

A factorial experimental design was utilized to determine which variable influenced the compliance rate the most. The results revealed that major roadway volume significantly affected compliance rate. In addition, the interaction effect of major roadway volumes and minor road sight distance significantly affected compliance rate. Intersection geometry type was determined not to contribute to the rate of compliance. From the results, Mounce recommended that STOP signs should be installed on minor streets where major street volumes are low to improve throughput.[21]

In 2012, Woldeamanuel conducted an observational study to examine how drivers' behavior at STOP-controlled intersections is affected by different sociodemographic and physical attributes. The variables used in this study included gender, age, number of passengers, time of day, urban setting, presence of law enforcement and headlight usage. A total of 2,400 observations were made at four major intersections in the Saint Cloud, Minnesota area. The stop events were classified as complete, rolling or no stop. The results of the study revealed that 35% of the drivers made a complete stop, whereas 65% of them did not make a complete stop (52% making a rolling stop and 13% not making any stop at all). Five of the variables (age, number of passengers in the vehicle, time of day, presence of law enforcement and headlight usage) were found to significantly influence the behavior of drivers. The results indicate that older drivers were more likely to comply with STOP signs at intersections. In addition, the likelihood of making a complete stop increased with the number of passengers in the vehicle. It was also more likely that drivers would come to a complete stop at night than during the day. The results showed that presence of police enforcement increased the likelihood of drivers coming to a complete stop. Finally, the likelihood of drivers making a complete stop decreased with less headlight usage.[22]

FACTORS INFLUENCING NONCOMPLIANCE AT SIGNALIZED INTERSECTIONS

Noncompliance is not limited to unsignalized intersections. In 2006, Huey and Ragland examined the effects of pedestrian countdown signals on driver behavior at two intersections with similar traffic flow, geometry and lane configurations in Berkeley, California. Approximately 80 traffic cycles were observed each day for two days at both locations. One intersection had pedestrian countdown signals and the other had traditional pedestrian signals. The results showed that the information provided by pedestrian countdown intersections allowed drivers to either increase their speed, maintain their speed, or decelerate in order to stop and wait for the next phase as they approached the intersection. On the other hand, when approaching a traditional intersection, drivers had less information resulting in "last second" attempts to cross at the end of the yellow interval. The study concluded that countdown pedestrian signals have both positive and negative effects on the drivers' behavior. The additional information allows drivers to make informed decisions about whether to maintain their speed or slow down and avoid taking risks trying to "catch the light." However, drivers may feel more comfortable entering the intersection at higher speeds, making them less able to avoid an unexpected vehicle or pedestrian and potentially cause an increase in red-light running.[23]

In 2010, Elmitiny investigated how certain variables affect a driver's decision to stop or go on a red light at intersections. The variables included distance of the vehicle from the STOP line, speed, yellow light entry time, whether the vehicle was in the lead or following position, lane position, and vehicle type. The study intersection was located on a high-speed corridor in a Central Florida suburb. Data was collected using a three-camera video-based system which recorded drivers' behavior associated with traffic signal change. A total of 1,292 vehicle observations were made. The results of the statistical analysis showed that the speeds of vehicles significantly affected drivers' decision to stop or go. Vehicles which approached the intersection at higher speed were more likely to violate the red light. In addition, the probability of a stop decision increased as the distance of the vehicle from the STOP line increased. Drivers within 280 ft. to 320 ft. of the intersection had probabilities of both stop and go decisions close to 0.5. This implies that vehicles within this interval showed the largest variability in their decision to stop or go during the yellow phase interval. Additionally, 90% of red-light-violators were within the 210 ft. to 480 ft. range of the intersection.[24]

In 2013, Chuanyun et al. also examined the contributing factors affecting compliance with traffic signs and signals. The study concluded that at signalized intersections, incoming drivers are usually puzzled whether to speed up or slow down when the traffic signal changes from green to yellow. If they are far from the traffic signal, they tend to speed through the intersection and this may lead to a traffic signal violation. If they suddenly slow down, it may result in rear-end collision.[25]

COUNTERMEASURES FOR TRAFFIC CONTROL SIGNS AND STOP SIGN VIOLATIONS

Various measures have been tested to mitigate the violation of traffic control signals and STOP signs. In 2009, Rice and Polanis showcased low-cost plans to improve safety at four STOP-controlled intersections in Winston-Salem, North Carolina. Various measures were taken to improve visibility and pavement markings at the intersections. These included the replacement of existing 24-inch STOP signs with 30-inch STOP signs, installing "STOP AHEAD" signs before the STOP signs, and providing double yellow centerlines and stop bar pavement markings. This treatment reduced crashes by 56.7% and improved throughput.[26]

Recently, advanced techniques including the use of infrastructure and vehicle-based collision avoidance systems are being implemented to increase compliance. These systems utilize roadside sensors, processors, warning devices, roadside-vehicle communication devices and other roadside informational and warning devices to provide driving assistance to road users. Currently, connected vehicle-based approaches are being proposed to improve throughput at intersections. These technologies enable the real time sharing of vehicle data such as position, speed and acceleration.[27]

IV. RESEARCH METHODOLOGY

SELECTION OF STUDY SEGMENTS

A total of 30 segments located on arterial and collector roads were selected in the District of Columbia for this study. Each segment consists of at least two signalized intersections and one AWSC intersection. The segments are such that no two signalized intersections are successive, with at most two AWSC intersections in between. A typical segment configuration is presented in Figure 1. The list of intersections selected for this study is presented in Table 4 and in Figure 2.

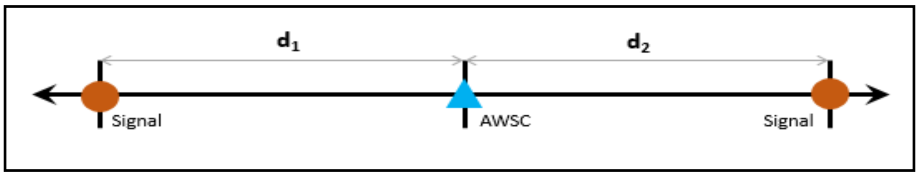


Figure 1. Study Segment Configuration

Table 4. List of Selected Segments in the District of Columbia

	Main Street	From	To
1	Albemarle Street NW	Nebraska Avenue NW	Reno Road NW
2	Van Ness Street NW	Wisconsin Avenue NW	Reno Road NW
3	Macomb Street NW	Wisconsin Avenue NW	Thirty-fourth Street NW
4	Woodley Road NW	Wisconsin Avenue NW	Thirty-fourth Street NW
5	S Street NW	Eighteenth Street NW	Sixteenth Street NW
6	O Street NW	Thirteenth Street NW	Eleventh Street NW
7	T Street NW	Thirteenth Street NW	Vermont Avenue NW
8	Eleventh Street NW	Florida Avenue NW	U Street NW
9	Thirteenth Street NW	Harvard Street NW	Euclid Street NW
10	Fairmont Street NW	Fourteenth Street NW	Sherman Street NW
11	Warder Street NW	Otis Place NW	Kenyon Street NW
12	Taylor Street NW	Fourteenth Street NW	Georgia Avenue NW
13	Upshur Street NW	Ninth Street NW	New Hampshire Avenue NW
14	Decatur Street NW	Sixteenth Street NW	Fourteenth Street NW
15	Thirteenth Street NW	Colorado Avenue NW	Kennedy Street NW
16	Sheridan Street NW	Georgia Avenue NW	Fifth Street NW
17	Aspen Street NW	Piney Branch Road NW	Blair Road NW
18	Fifth Street NW	Cedar Street NW	Van Buren Street NW
19	North Dakota Avenue NW	Sheridan Street NW	Peabody Street NW
20	Sargent Street NE	South Dakota Avenue NE	Varnum Street NE
21	Twentieth Street NE	Monroe Street NE	Rhode Island Avenue NE
22	Third Street NE	Florida Avenue NE	K Street NE
23	Fifth Street NE	Florida Avenue NE	K Street NE
24	Sixth Street NE	M Street, NE	K Street NE
25	Seventh Street NE	Florida Avenue NE	K Street NE

	Main Street	From	To
26	Eleventh Street NE	Maryland Avenue NE	C Street NE
27	Thirteenth Street NE	Maryland Avenue NE	C Street NE
28	Fourteenth Street NE	Maryland Avenue NE	C Street NE
29	Ninth Street SE	E Capitol Street SE	Independence Avenue SE
30	G Street SE	Eighth Street SE	Eleventh Street SE

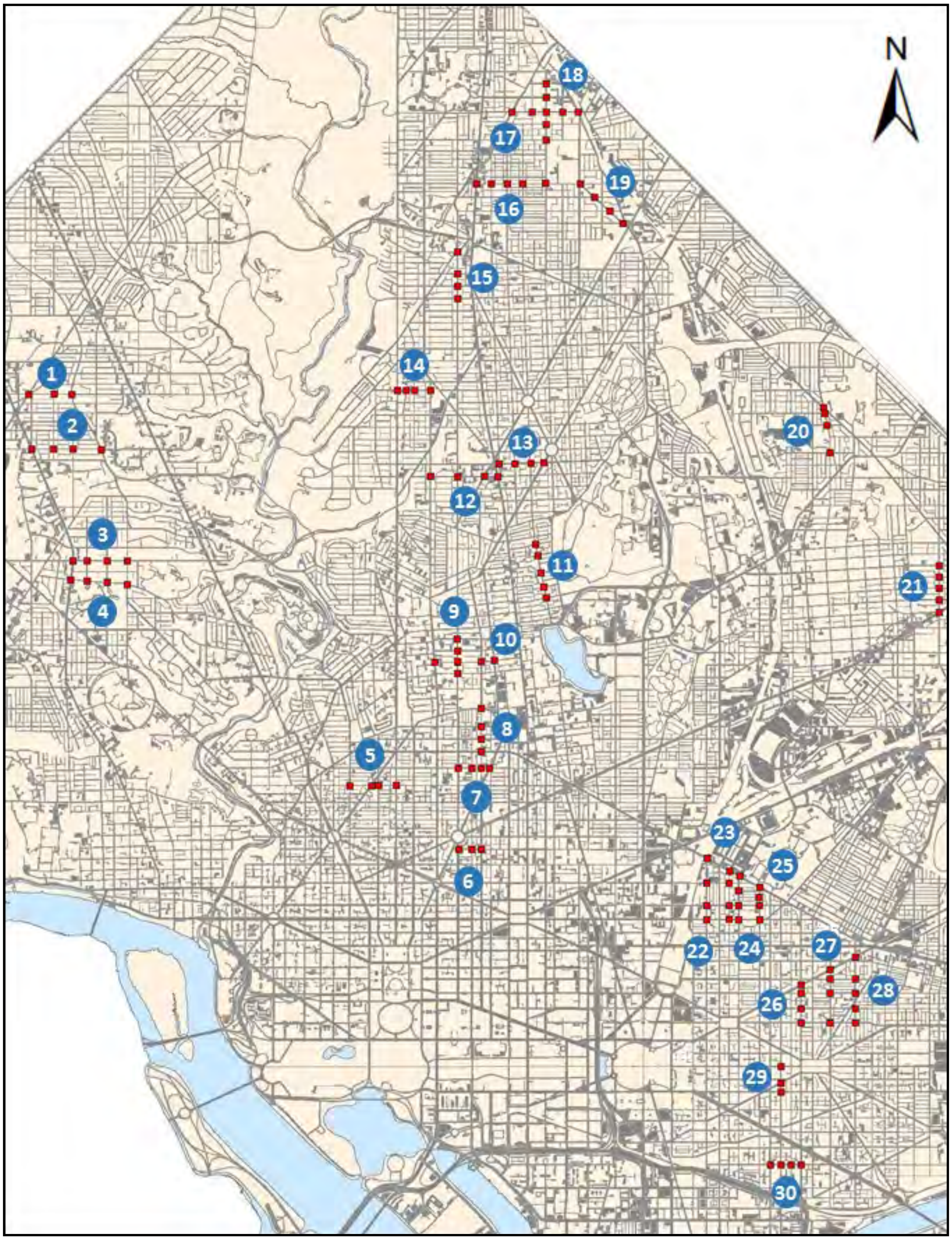


Figure 2. Selected Segments in the District of Columbia

FIELD ASSESSMENT/EXISTING CONDITIONS

A field assessment was conducted between April and December 2017 to obtain inventory of existing conditions at all the intersection and their approaches along the selected segments. The information gathered in the field included the geometric characteristics of the approaches, pavement type, existing signs and markings conditions, and presence of parking restrictions. Pedestrian and vehicular activities were also observed. The existing conditions along the segments and their intersections are described in the next sections.

Albemarle Street, NW between Nebraska Avenue and Reno Road, NW

This segment consists of three intersections located in the Northwest quadrant of the District of Columbia. The main segment, Albemarle Street, NW, is classified as a collector road and is located in a residential area. Albemarle Street, NW is a bidirectional street (one lane per direction) which runs in the east-west direction. It is approximately 1,358 feet long and 32 feet wide (curb to curb) with on-street parking on both sides of the street. The following intersections are located within this segment.

Albemarle Street and Nebraska Avenue, NW

The intersection of Albemarle Street and Nebraska Avenue, NW is signalized. Nebraska Avenue, NW is a bidirectional principal arterial road with two lanes per direction and runs in the north-south orientation. The road is approximately 37 feet wide (curb to curb) with restricted parking on both sides. The posted speed on Nebraska Avenue, NW is 30 mph.

Albemarle Street and Thirty-Eighth Street, NW

Albemarle Street and Thirty-Eighth Street, NW is an AWSC intersection. Thirty-Eighth Street, NW is a bidirectional local street with one lane per direction and runs in the north-south orientation. The road is approximately 30 feet wide (curb to curb) with residential parking on both sides. The posted speed limit on Thirty-Eighth Street is 25 mph.

Albemarle Street and Reno Road, NW

The intersection of Albemarle Street and Reno Road, NW is signalized. Reno Road, NW is classified as a minor arterial bidirectional road with one lane per direction and runs in the north-south orientation. It is approximately 37 feet wide (curb to curb), with no parking on either side of the street. The posted speed limit on Reno Road is 25 mph.

Van Ness Street, NW between Wisconsin Avenue and Reno Road, NW

The study segment consists of four intersections located in a residential area in the northwest quadrant of the District of Columbia. The main segment, Van Ness Street, NW is a bidirectional collector road with one lane per direction and runs in an east-west direction. The road is approximately 2,190 feet long and 36 feet wide (curb to curb) and includes on-street parking on the north side of the road. The posted speed limit on Van Ness Street, NW is 25 mph. The following intersections are located within this segment.

Van Ness Street and Wisconsin Avenue, NW

The intersection of Van Ness Street and Wisconsin Avenue, NW is signalized. Wisconsin Avenue, NW is a bidirectional principal arterial road which runs in the north-south orientation. The road is approximately 63 feet wide (curb to curb) with on-street parking on one side of the street. The posted speed limit on Wisconsin Avenue, NW is 30 mph.

Van Ness Street and Thirty-Eighth Street, NW

The intersection of Van Ness Street and Thirty-Eighth Street, NW is unsignalized and controlled by All-Way STOP signs on all approaches. Thirty-Eighth Street, NW is a bidirectional local street which runs in the north-south orientation. It is approximately 29 feet wide (curb to curb), with on-street parking on both sides. The posted speed limit on Thirty-Eighth Street, NW is 25 mph.

Van Ness Street and Thirty-Seventh Street, NW

The intersection of Van Ness Street and Thirty-Seventh Street, NW is unsignalized and controlled by All-Way STOP signs on all approaches. Thirty-Seventh Street, NW is a bidirectional local street which runs in the north-south orientation. The road is approximately 32 feet wide (curb to curb), with on-street parking on both sides of the street. The posted speed limit on Thirty-Seventh Street, NW is 25 mph.

Van Ness Street and Reno Road, NW

Van Ness Street and Reno Road, NW is a signalized intersection. Reno Road, NW is a bidirectional minor arterial street which runs in the north-south orientation, approximately 32 feet wide (curb to curb), with no-street parking on either side of the street. The posted speed limit on Reno Road, NW is 25 mph.

Macomb Street, NW between Wisconsin Avenue and Thirty-Fourth Street, NW

The study segment consists of four intersections located in a residential area in the northwest quadrant of the District of Columbia. The main segment, Macomb Street, NW, is a bidirectional road oriented in the east-west direction and is classified as a local roadway. Macomb Street, NW has permitted on-street parking on both sides and a posted speed limit of 25 mph. The length and width of the segment is approximately 1,720 feet long and 30 feet wide (curb to curb). The following intersections are located within the segment.

Macomb Street and Wisconsin Avenue, NW

The intersection of Macomb Street and Wisconsin Avenue, NW is signalized. Wisconsin Avenue, NW is a bidirectional minor arterial with two lanes per direction, and it is oriented in the north-south direction. The road is approximately 60 feet wide (curb to curb) and has permitted on street parking on both sides of the street. This intersection has restricted right turns on red signal. The posted speed limit on Wisconsin Avenue, NW is 30 mph.

Macomb Street and Thirty-Sixth Street, NW

The intersection of Macomb Street and Thirty-Sixth Street, NW is unsignalized and controlled by All-Way STOP signs on all approaches. Thirty-Sixth Street, NW is a bidirectional local road with one lane per direction. It also has a north-south direction with on-street parking on both sides of the street and a posted speed limit of 25 mph. Thirty-Sixth street is approximately 30 feet wide (curb to curb).

Macomb Street and Thirty-Fifth Street, NW

The intersection of Macomb Street and Thirty-Fifth Street, NW is unsignalized and controlled by All-Way STOP signs on all approaches. Thirty-Fifth Street, NW is a bidirectional local road with one lane per direction and is oriented in the north-south direction. In addition, it is approximately 30 feet wide and has on-street parking on both sides of the street. Thirty-fifth Street, NW has a posted speed limit of 25 mph.

Macomb Street and Thirty-Fourth Street, NW

The intersection of Macomb Street and Thirty-Fourth Street NW is signalized. Thirty-Fourth Street, NW is a bidirectional local road with one lane per direction and has a north-south orientation. The road is approximately 30 feet wide (curb to curb), and there is permitted on-street parking on both sides of the street. The northbound and southbound approaches have two receiving lanes, of which one is a left-turn storage lane.

Woodley Street, NW between Wisconsin Avenue and Thirty-Fourth Street, NW

The study segment consists of four intersections located in a residential area in the northwest quadrant of the District of Columbia. The main segment, Woodley Street, NW is a bidirectional road oriented in the east-west direction and is classified as a local roadway. Woodley Street, NW has permitted on-street parking on both sides of the street and a posted speed limit of 25 mph. The segment is approximately 1,785 feet long and 30 feet wide (curb to curb). The following intersections are located within the segment.

Woodley Street and Wisconsin Avenue, NW

The intersection of Woodley Street and Wisconsin Avenue, NW is signalized. Wisconsin Avenue, NW is a bidirectional minor arterial with three lanes per direction, and it is oriented in the north-south direction. The road is approximately 60 feet wide (curb to curb) and has permitted on-street parking on both sides of the street. In addition, right turns are restricted on red signal. The posted speed limit on Wisconsin Avenue, NW is 30 mph.

Woodley Street and Thirty-Sixth Street, NW

The intersection of Woodley Street and Thirty-Sixth Street, NW is unsignalized and controlled by All-Way STOP signs on all approaches. Thirty Sixth Street, NW is a bidirectional local road with one lane per direction and is oriented in the north-south direction. Thirty-Sixth Street is approximately 30 feet wide (curb to curb) with on-street parking on both sides and a posted speed limit of 25 mph.

Woodley Street and Thirty-Fifth Street, NW

The intersection of Woodley Street and Thirty-Fifth Street, NW is controlled by All-Way STOP signs on all approaches. Thirty-Fifth Street, NW is a bidirectional local road with one lane per direction and is oriented in the north-south direction. Thirty-Fifth Street is approximately 30 feet wide (curb to curb) with on-street parking on both sides and a posted speed limit of 25 mph.

Woodley Street and Thirty-Fourth Street, NW

Woodley Street and Thirty-Fourth Street, NW is controlled by a traffic signal. Thirty-Fourth Street, NW is a bidirectional local road with one lane per direction and is oriented in the north-south direction. The road is approximately 30 feet wide (curb to curb), and on-street parking is not permitted near the north- and southbound approaches. The northbound and southbound approaches have two receiving lanes of which one is a left turn storage lane.

S Street, NW between Eighteenth Street and Sixteenth Street, NW

The study segment consists of four intersections located in a mixed-use-residential area in the northwest quadrant of the District of Columbia. The main segment, S Street, NW, is a bidirectional street oriented in the east-west direction and is classified as a local roadway. S Street, NW has permitted on-street parking on both sides of the street and a posted speed limit of 25 mph. The segment is approximately 1,470 feet long and 32 feet wide (curb to curb). The following intersections are located within the segment.

S Street and Eighteenth Street, NW

The intersection of S Street and Eighteenth Street, NW is signalized. Eighteenth Street, NW is a minor arterial roadway with a north-south orientation and one lane per direction. There is designated on-street parking on both sides of the north leg and on one side of the south leg of the intersection. The segment is approximately 32 feet wide (curb to curb), with a posted speed limit of 25 mph.

S Street and New Hampshire Avenue, NW

The intersection of S Street and New Hampshire Avenue, NW is unsignalized and controlled by All-Way STOP signs on all approaches. New Hampshire Avenue, NW is a minor arterial roadway with a northeast-southwest orientation and one lane per direction. There are bicycle lanes and designated on-street parking permitted on both sides of the street, with a posted speed limit of 25 mph. The width of the segment is approximately 50 feet (curb to curb).

S Street and Seventeenth Street, NW

S Street and Seventeenth Street, NW is controlled by All-Way STOP signs on all approaches. Seventeenth Street, NW is a one-way minor arterial roadway that runs in the southbound direction and has two lanes per direction. There is permitted on-street parking on both sides of the street and a bicycle lane on one side of the street. The width of the segment is approximately 43 feet (curb to curb), with a posted speed limit of 25 mph.

S Street and Sixteenth Street, NW

The intersection of S Street and Sixteenth Street, NW is signalized. Sixteenth Street, NW is a principal arterial with a north-south orientation and two lanes per direction. There is permitted on-street parking on both sides, with a posted speed limit of 25 mph. The width of the segment is approximately 48 feet (curb to curb).

O Street, NW between Thirteenth Street and Eleventh Street, NW

The study segment consists of three intersections located in a residential area in the northwest quadrant of the District of Columbia. The main segment, O Street, NW, is a bidirectional road oriented in the east-west direction and is classified as a local road. O Street, NW has permitted on-street parking on both sides of the street and a posted speed limit of 25 mph. The segment is approximately 735 feet long and 31 feet wide (curb to curb). The following intersections are located within the segment.

O Street and Thirteenth Street, NW

The intersection of O Street and Thirteenth Street, NW is controlled by a traffic signal. Thirteenth Street, NW is a bidirectional minor arterial roadway with two lanes per direction, which runs in the north-south orientation. The road is approximately 69 feet wide (curb to curb) and has designated on-street parking and bicycle lanes on both sides of the street. At the Intersection, the eastbound approach of O Street, NW is a one-way street, whereas the westbound approach is a bidirectional road.

O Street and Twelfth Street, NW

The intersection of O Street and Twelfth Street, NW is unsignalized and controlled by All-Way STOP signs on all approaches. Twelfth Street, NW is a one-way lane collector road which runs in the northbound direction. The width of the road is approximately 31 feet (curb to curb). It has a bicycle lane on one side and designated on-street parking on both sides of the street.

O Street and Eleventh Street, NW

The intersection of O Street and Eleventh Street, NW is signalized. Eleventh Street, NW is a bidirectional minor arterial roadway with one lane per direction, which runs in the north-south orientation. The width of the street is approximately 58 feet (curb to curb), and it has designated on-street parking and bicycle lanes on both sides of the street. Both approaches of Eleventh Street, NW have a left-turn storage lane.

T Street, NW between Thirteenth Street and Vermont Avenue, NW

The study segment consists of four intersections located in a residential area in the Northwest quadrant of the District of Columbia. The main segment, T Street, NW, is a one-way local street which runs in an eastbound direction and is approximately 988 feet long and 32 feet wide (curb to curb). There is on-street parking on both sides and a bicycle lane on one side of the street. Vehicles over 1.25 tons are restricted from entering T Street, NW. The following intersections are located within this segment.

T Street and Thirteenth Street, NW

The intersection of T Street and Thirteenth Street, NW is signalized. Thirteen Street, NW is classified as a minor arterial road at the study intersection. It is a bidirectional street which runs in the north-south orientation, and it is approximately 43 feet wide (curb to curb), with restricted parking on both sides of the street. The posted speed limit of Thirteenth Street, NW is 25 mph.

T Street and Twelfth Street, NW

The intersection of T Street and Twelfth Street, NW is unsignalized and controlled by All-Way STOP signs on all approaches. Twelfth Street, NW is a bidirectional local street which runs in the north-south orientation. The road is approximately 33 feet wide (curb to curb) and has on-street parking on both sides of the street. The posted speed limit on both streets is 25 mph.

T Street and Eleventh Street, NW

The intersection of T Street and Eleventh Street, NW is unsignalized and controlled by STOP signs. Eleven Street, NW is a bidirectional local street which runs in the north-south orientation. It is approximately 34 feet wide (curb to curb) and has street parking on both sides. The posted school zone speed limit for Eleventh Street, NW is 15 mph.

T Street and Vermont Avenue, NW

The intersection of T Street and Vermont Avenue, NW is signalized. Vermont Avenue, NW is a bidirectional collector street with two lanes per direction, which runs in the northwest and southeast orientation. The road is approximately 80 feet wide from curb to curb and 28 feet wide from median to curb. Vermont Avenue, NW has on-street parking on both sides of the street and has a posted school zone speed limit of 15 mph.

Eleventh Street, NW between Florida Avenue and U Street, NW

The study segment consists of four intersections located in a mixed-use area in the northwest quadrant of the District of Columbia. The main segment, Eleventh Street, NW, is a bidirectional collector road that is oriented in the north-south direction. Eleventh Street, NW has permitted on-street parking on both sides of the street and a posted speed limit of 25 mph. The segment is approximately 1,370 feet long and 32 feet wide (curb to curb). The following intersections are located within this segment.

Eleventh Street and Florida Avenue, NW

The intersection of Eleventh Street and Florida Avenue, NW is controlled by a traffic signal. Florida Avenue, NW is classified as a bidirectional principal arterial roadway with one lane per direction and is oriented in the east-west direction. The road is approximately 34 feet wide and has permitted on-street parking on both sides of the street. Florida Avenue, NW has a speed limit of 25 mph.

Eleventh Street and W Street, NW

The intersection of Eleventh Street and W Street, NW is controlled by All-Way STOP signs on all approaches. W Street, NW is a one-way local roadway that runs in the eastbound direction. The road is approximately 32 feet wide and has permitted on-street parking on both sides of the street. W Street, NW has a speed limit of 25 mph.

Eleventh Street and V Street, NW

The intersection of Eleventh Street and V Street, NW is controlled by All-Way STOP signs on all approaches. V Street, NW is a one-way local roadway that runs in the westbound direction. The road is approximately 30 feet wide and has on-street parking on both sides of the street. V Street, NW has a speed limit of 25 mph.

Eleventh Street and U Street, NW

The intersection of Eleventh Street and U Street, NW is controlled by a traffic signal. U Street, NW is a bidirectional principal arterial road with two lanes per direction. The road has an east-west orientation and has on-street parking on both sides of the street. The road is approximately 60 feet wide (curb to curb) and has a posted speed limit of 25 mph.

Thirteenth Street, NW between Harvard Street and Euclid Street, NW

The study segment consists of four intersections located in a residential area in the northwest quadrant of the District of Columbia. The main segment, Thirteenth Street, NW, is a bidirectional minor arterial roadway with one lane per direction that is oriented in the north-south direction. The segment is approximately 1,084 feet long and 40 feet wide and has permitted on-street parking on both sides of the street. Thirteenth Street, NW has a posted speed limit of 25 mph. The following intersections are located within the segment.

Thirteenth Street and Harvard Street, NW

The intersection of Thirteenth Street and Harvard Street, NW is controlled by a traffic signal. Harvard Street, NW is classified as a one-way minor arterial road that is oriented in an eastbound direction. The roadway is approximately 30 feet wide (curb to curb) and has permitted on-street parking on both sides of the street. Harvard Street, NW has a posted speed limit of 25 mph.

Thirteenth Street and Girard Street, NW

Thirteenth Street and Girard Street, NW is controlled by All-Way STOP signs on all approaches. Girard Street, NW is classified as a bidirectional local road with one lane per direction that is oriented in the east-west direction. The roadway is approximately 30 feet wide (curb to curb) and has permitted on-street parking on both sides of the road. Girard Street, NW has a posted speed limit of 25 mph.

Thirteenth Street and Fairmont Street, NW

The intersection of Thirteenth Street and Fairmont Street, NW is unsignalized and controlled by an All-Way STOP Control. Fairmont Street, NW is classified as a local road with a posted speed limit of 25 mph and on-street parking on both sides. Fairmont Street, NW is bidirectional (one lane per direction) with an east-west orientation and is approximately 30 ft. wide (curb to curb).

Thirteenth Street and Euclid Street, NW

The intersection of Thirteenth Street and Euclid Street, NW is signalized. Euclid Street, NW is classified as a collector road with a posted speed limit of 25 mph. It has on-street parking on both sides of the street. Euclid Street, NW is a bidirectional street with one lane per direction and is oriented in the east-west direction. The width of the segment is approximately 30 ft. wide (curb to curb).

Fairmont Street, NW between Fourteenth Street and Sherman Street, NW

This segment consists of four intersections located in a residential area in the northwest quadrant of the District of Columbia. The main segment, Fairmont Street, NW is a bidirectional local road oriented in the east-west direction. It has on-street permitted parking on both sides and a posted speed limit of 25 mph. The length and width of the segment is approximately 1,860 feet and 30 feet (curb to curb), respectively. The study segment consists of the following intersections.

Fairmont Street and Fourteenth Street, NW

The T intersection of Fairmont Street and Fourteenth Street, NW is signalized. Fourteenth Street is a bidirectional minor arterial oriented in the north-south direction. It has on-street parking on both sides of the street and is approximately 55 feet wide (curb to curb). The northbound and southbound approaches of the intersection have two receiving lanes, of which one is a left turn storage lane. Both approaches have bicycle lanes located between the travel and parking lanes. The eastbound approach of the intersection has one receiving lane with restricted parking near the approach of the intersection.

Fairmont Street and Thirteenth Street, NW

The intersection of Fairmont Street and Thirteenth Street, NW is controlled by All-Way STOP signs. Thirteenth Street NW is a bidirectional minor arterial with a north-south orientation and has designated on-street parking on both sides. The street is 40 feet wide (curb to curb) and has a posted speed limit of 25 mph.

Fairmont Street and Eleventh Street, NW

The intersection of Fairmont Street and Eleventh Street, NW is controlled by All-Way STOP signs. Eleventh Street, NW is a bidirectional collector road oriented in the north-south direction with designated on-street parking on both sides. Both the northbound and southbound approaches have bicycle lanes located between the travel and parking lanes. The width of the segment is approximately 45 feet wide (curb to curb).

Fairmont Street and Sherman Street, NW

The intersection of Fairmont Street and Sherman Street, NW is signalized. Sherman Street is a bidirectional minor arterial that is oriented in the north-south direction. It has one lane per direction with designated on-street parking on both sides. The opposing lanes are separated by a raised median. The segment is approximately 50 feet wide (curb to curb). The southbound approach has two receiving lanes, a through lane and a right-turn storage lane. Also, the northbound approach has two receiving lanes, a through lane and a left turn storage lane. The westbound approach of Fairmont Street is a one-way street with a single travel lane.

Warder Street, NW between Kenyon Street and Otis Place, NW

This segment consists of five intersections located in the northwest quadrant of the District of Columbia. The main segment, Warder Street, NW, is a one-way collector street which runs in a northbound direction and is approximately 1,725 feet long and 33 feet wide (curb to curb). There is on-street parking on both sides and a bicycle lane on one side of the road. The study segment is located in a residential area with a few markets, a school, and a recreation center. The following intersections are located within the segment.

Warder Street and Kenyon Street, NW

The intersection of Warder Street and Kenyon Street, NW is controlled by a traffic signal. Kenyon Street, NW is a one-way minor arterial road which runs in the east-west orientation. It is 29 feet wide (curb to curb) with on-street parking on one side of the street.

Warder Street and Lamont Street, NW

The intersection of Warder Street and Lamont Street, NW is unsignalized and controlled by All-Way STOP signs. Lamont Street, NW is a bidirectional street which runs in the east-west orientation. It is approximately 32 feet wide (curb to curb) with on-street parking on both sides.

Warder Street and Park Road, NW

The intersection of Warder Street and Park Road, NW is controlled by All-Way STOP signs on all approaches. Park Road, NW is a bidirectional local street which runs in the east-west orientation. It is approximately 29 feet wide (curb to curb) with on-street parking on one side of the road. The posted speed limit on Park Road, NW is 15 mph.

Warder Street and Newton Place, NW

The intersection of Warder Street and Newton Place, NW is unsignalized and controlled by All-Way STOP signs. Newton Place, NW is a one-way local road which runs in the eastbound direction. It is approximately 27 feet wide (curb to curb) with on-street parking on both sides.

Warder Street and Otis Place, NW

Warder Street and Otis Place, NW is a signalized intersection. Otis Place, NW is a one-way local road which runs in the westbound direction. It is approximately 31 feet wide (curb to curb) with on-street parking on both sides.

Taylor Street, NW between Georgia Avenue and Fourteenth Street, NW

This segment consists of four intersections located in a residential area in the northwest quadrant of the District of Columbia. The main segment, Taylor Street, NW, is a bidirectional street which runs in an east-west direction, approximately 2,135 feet long and 33 feet wide (curb to curb), with street parking on both sides of the road. On Taylor Street, NW traffic flows with one lane per direction. The following intersections are located within the segment.

Taylor Street and Georgia Avenue, NW

The intersection of Taylor Street and Georgia Avenue, NW is signalized. Georgia Avenue, NW is a bidirectional principal arterial road which runs in the north-south orientation. It is approximately 65 feet wide (curb to curb) with on-street metered parking on both sides. On Georgia Avenue, NW traffic flows on two lanes per direction. The posted speed limit on both street is 25 mph.

Taylor Street and Kansas Avenue, NW

The intersection of Taylor Street and Kansas Avenue, NW is unsignalized and controlled by an All-Way STOP. Kansas Avenue, NW is a bidirectional minor arterial road which runs in the northwest and southeast orientation. It is approximately 40 feet wide (curb to curb) with street parking on both sides. At the study intersection, the posted speed limit on Taylor Street, NW is 15 mph, while the posted speed limit for Kansas Avenue, NW is 25 mph.

Taylor Street and Thirteenth Street, NW

Taylor Street and Thirteenth Street, NW is unsignalized and controlled by All-Way STOP signs. Thirteen Street, NW is a bidirectional minor arterial road which runs in the north-south orientation, approximately 43 feet wide (curb to curb) with restricted parking on both sides of the road. The posted speed limit on both street is 25 mph.

Taylor Street and Fourteenth Street, NW

Taylor Street and Fourteenth Street, NW is a signalized intersection. Fourteen Street, NW is a bidirectional minor arterial road which runs in the north-south orientation, approximately 48 feet wide (curb to curb) with on-street parking and bicycle lanes on both sides of the street. Traffic on Fourteenth Street, NW, flows by with one lane per direction.

Upshur Street, NW between Ninth Street and New Hampshire Avenue, NW

The study segment consists of four intersections located in the northwest quadrant of the District of Columbia. The main segment, Upshur Street, NW is a bidirectional collector street with one lane per direction. It has a bicycle lane and designated on-street parking on both sides of the street. Upshur Street, NW runs in the east-west orientation and is approximately 1,380 feet long and 48 feet wide (curb to curb). The study segment is located in a residential area with a few markets and diners. The following intersections are located within this segment.

Upshur Street and Ninth Street, NW

The intersection of Upshur Street and Ninth Street, NW is signalized. Ninth Street, NW is a one-way local street with one lane per direction. It runs in the north-south orientation and is approximately 29 feet wide (curb to curb). The posted speed limit is 25 mph. On-street parking is permitted on both sides of the north leg and only on one side of the south leg of the intersection.

Upshur Street and Eighth Street, NW

The intersection of Upshur Street and Eighth Street, NW is controlled by All-Way STOP signs. Eighth Street, NW is a bidirectional local street with one lane per direction, and it runs in the north-south direction. It is approximately 31 feet wide (curb to curb) and has a posted speed limit of 25 mph, with on-street parking on both sides.

Upshur Street and Seventh Street, NW

Upshur Street and Seventh Street, NW is an unsignalized intersection controlled by STOP signs on all approaches. Seventh Street, NW is a one-way local street which runs in the northbound direction. It is approximately 29 feet wide (curb to curb) with a bicycle lane. The posted speed limit is 25 mph, with designated on-street parking on both sides and a bicycle lane on one side of the street.

Upshur Street and New Hampshire Avenue, NW

The intersection of Upshur Street and New Hampshire Avenue, NW is signalized. New Hampshire Avenue, NW is a bidirectional minor arterial road with two lanes per direction. It runs in the northeast-southwest direction and is approximately 29 feet wide (curb to curb). It has a posted speed limit of 30 mph, with on-street parking on both sides of the street.

Decatur Street, NW between Sixteenth Street and Fourteenth Street, NW

The study segment consists of four intersections located in the northwest quadrant of the District of Columbia. The main segment, Decatur Street, NW, is a bidirectional collector road oriented in the east-west direction. Decatur Street, NW has permitted on-street parking on both sides of the street and a school-zone posted speed limit of 15 mph. The segment is approximately 1,046 feet long and 29 feet wide (curb to curb). The segment is located in a residential area which has a few markets, a school, and a few religious places of worship. The study segment consists of the following intersections.

Decatur Street and Sixteenth Street, NW

The intersection of Decatur Street and Sixteenth Street, NW is signalized. Sixteenth Street, NW is a principal arterial with a north-south orientation and two lanes per direction. Parking is restricted on either side of the street from 7 a.m. – 9:30 a.m. and 4 p.m. – 6:30 p.m., Monday to Friday. The width of the segment is approximately 48 feet (curb to curb).

Decatur Street and Piney Branch Road, NW

The intersection of Decatur Street and Piney Branch Road, NW is controlled by All-Way STOP signs. Piney Branch Road, NW is a local road which runs in the northeast-southwest orientation and has one lane per direction. It is approximately 24 feet wide (curb to curb) and has residential parking on one side of the street.

Decatur Street and Fifteenth Street, NW

The intersection of Decatur Street and Fifteenth Street, NW is unsignalized and controlled by All-Way STOP signs. Fifteenth Street, NW is a local road that runs north-south and has one lane per direction. It is approximately 30 feet wide (curb to curb) and has permitted residential parking on both sides.

Decatur Street and Fourteenth Street, NW

The intersection of Decatur Street and Fourteenth Street, NW is signalized. Fourteenth Street, NW is a minor arterial with a north-south orientation and one lane per direction. There is a dedicated parking space and bicycle lane on each side. It is approximately 40 feet wide (curb to curb) and has a posted speed limit of 25 mph.

Thirteenth Street, NW between Colorado Avenue and Kennedy Street, NW

This segment consists of four intersections located in a residential area in the northwest quadrant of the District of Columbia. The main segment, Thirteenth Street, NW, is a bidirectional street that is oriented in the north-south direction and is classified as a minor arterial roadway according to DC's Functional Classification Map. Thirteenth Street, NW has permitted on-street parking on both sides and a posted speed limit of 25 mph. The length and width of the corridor are 1,460 feet and 40 feet (curb to curb), respectively. The study segment consists of the following intersections.

Thirteenth Street and Colorado Avenue, NW

The intersection of Thirteenth Street and Colorado Avenue, NW is controlled by a traffic signal. Colorado Avenue, NW is classified as a collector road with a posted speed limit of 25 mph and has on-street parking on both sides. Colorado Avenue, NW is a 45 feet wide (curb to curb) bidirectional road with one lane per direction and a northeast-southwest orientation.

Thirteenth Street and Madison Street, NW

The intersection of Thirteenth Street and Madison Street, NW is controlled by All-Way STOP signs. Madison Street, NW is a bidirectional local road with a posted speed limit of 25 mph and has on-street parking on both sides. Madison Street, NW has one lane per direction with an east-west orientation and is approximately 30 feet wide (curb to curb).

Thirteenth Street and Longfellow Street, NW

The intersection of Thirteenth Street and Longfellow Street, NW is controlled by All-Way STOP signs. Longfellow Street, NW is classified as a local road with a posted speed limit of 25 mph and has on-street parking on both sides. Longfellow Street, NW is a bidirectional road with one lane per direction that runs in an east-west orientation and is approximately 30 feet wide (curb to curb).

Thirteenth Street and Kennedy Street, NW

The intersection of Thirteenth Street and Kennedy Street, NW is signalized. Kennedy Street, NW is bidirectional (one lane per direction) with an east-west orientation and is approximately 40 feet wide (curb to curb). It is classified as a collector road with a posted speed limit of 25 mph and has on-street parking on both sides.

Sheridan Street, NW between Georgia Avenue and Fifth Street, NW

This segment consists of five intersections located in the northwest quadrant of the District of Columbia. The main segment, Sheridan Street, NW, is a bidirectional local street that is oriented in the east-west direction. It is approximately 2,185 feet long and 29 feet wide (curb to curb) with on-street parking on both sides. The study segment is located in a residential area with a few shops and a school on the corner of 5^{th} Street and Sheridan

Street, NW. The posted school-zone speed limit is 15 mph. The following intersections are located within the segment.

Sheridan Street, NW and Fifth Street, NW

The intersection of Sheridan Street and Fifth Street, NW is controlled by a traffic signal. Fifth Street, NW is a bidirectional collector street which runs in the north-south orientation. It is approximately 29 feet wide (curb to curb) with residential parking only on the west side of the street. The posted school-zone speed limit is 15 mph.

Sheridan Street, NW and Seventh Street, NW

The intersection of Sheridan Street and Seventh Street, NW is controlled by All-Way STOP signs. Seventh Street, NW is a bidirectional local street which runs in the north-south orientation. It is approximately 29 feet wide (curb to curb) with residential parking on both sides. The posted speed limit on Seventh Street, NW is 25 mph.

Sheridan Street, NW and Eighth Street, NW

The intersection of Sheridan Street and Eighth Street, NW is unsignalized and controlled by All-Way STOP signs. Eighth Street, NW is a bidirectional street which runs in the north-south orientation. It is approximately 27 feet wide (curb to curb) with residential parking on both sides of the street. The posted speed limit is 25 mph.

Sheridan Street, NW and Ninth Street, NW

The intersection of Sheridan Street and Ninth Street, NW is controlled by an All-Way STOP signs. Ninth Street, NW is a bidirectional street which runs in the north-south orientation. It is approximately 32 feet wide (curb to curb) with residential parking on both sides. The posted speed limit on 8th Street, NW is 25 mph.

Sheridan Street, NW and Georgia Avenue, NW

The intersection of Sheridan Street and Georgia Avenue, NW is signalized. Georgia Avenue, NW is classified as a principal arterial road at the study intersection. It is a bidirectional street which runs in the north-south orientation. It is approximately 65 feet wide (curb to curb) and has on-street metered parking on both sides. The posted speed limit on Georgia Avenue, NW is 30 mph.

Aspen Street, NW between Piney Branch Road and Blair Road, NW

The study segment consists of five intersections located in the northwest quadrant of the District of Columbia. The main segment, Aspen Street, NW, is a bidirectional road oriented in the east-west direction and is classified as a collector roadway according to DC's Functional Classification Map. Aspen Street, NW has on-street parking permitted on both sides and a posted speed limit of 25 mph. The length and width of the segment are approximately 2,096 feet and 29 feet (curb to curb). This residential area has markets, convenience stores, libraries, and a metro station nearby. There are also a religious places of worship in the surroundings. The study segment consists of the following intersections.

Aspen Street and Piney Branch Road, NW

The intersection of Aspen Street and Piney Branch Road, NW is signalized. Piney Branch Road, NW is a minor arterial road with a northeast-southwest orientation. The road has one lane per direction with dedicated parking lanes on both sides. The street is approximately 65 feet wide (curb to curb) with a posted speed limit of 25 mph.

Aspen Street and Sixth Street, NW

The intersection of Aspen Street and Sixth Street, NW is unsignalized and controlled by All-Way STOP signs. Sixth Street, NW is a bidirectional local road with one lane per direction and a north-south orientation. Sixth Street is approximately 28 feet wide (curb to curb) with residential parking on both sides and a posted speed limit of 25 mph.

Aspen Street and Fifth Street, NW

The intersection of Aspen Street and Fifth Street, NW is controlled by All-Way STOP signs. Fifth Street, NW is a bidirectional collector street with one lane per direction and a north-south orientation. Fifth Street is approximately 32 feet wide (curb to curb) with residential parking on both sides and a posted speed limit of 25 mph.

Aspen Street and Fourth Street, NW

The intersection of Aspen Street and Fourth Street, NW is controlled by All-Way STOP signs. Fourth Street, NW is a bidirectional collector street with one lane per direction and a north-south orientation. Fourth Street is approximately 30 feet wide (curb to curb) with residential parking on both sides and a posted speed limit of 25 mph.

Aspen Street and Blair Road, NW

The intersection of Aspen Street and Blair Road, NW is signalized. Blair Road, NW is a minor arterial road with a northwest-southeast orientation. The northwest direction has two lanes while the southwest has one. On-street parking is not permitted on either side of the street. Blair Road is approximately 31 feet wide (curb to curb) with a posted speed limit of 25 mph.

Fifth Street, NW between Cedar Street and Van Buren Street, NW

The study segment consists of five intersections located in the northwest quadrant of the District of Columbia. The main segment, Fifth Street, NW, is a bidirectional collector road oriented in the north-south direction. Fifth Street, NE has permitted on-street parking on both sides and a posted speed limit of 25 mph. The length and width of the segment are approximately 1,715 feet and 30 feet (curb to curb). The segment is located in a residential area with a few markets, a metro station, and a library on the corner of Cedar Street, NW. The intersections within this segment are presented below.

Fifth Street, NW and Cedar Street, NW

The intersection of Fifth Street and Cedar Street, NW is signalized. Cedar Street is a bidirectional local roadway with one lane per direction oriented in the east-west direction and a posted speed limit of 25 mph. The width of the segment is approximately 30 feet (curb to curb) with residential on-street parking on both sides.

Fifth Street, NW and Butternut Street, NW

The intersection of Fifth Street and Butternut Street, NW is controlled by All-Way STOP signs. Butternut Street is a bidirectional collector roadway with one lane per direction, and it is oriented in the east-west direction. It has a posted speed limit of 25 mph and is 45 feet wide (curb to curb) with designated residential on-street parking and bicycle lanes on both sides of the street.

Fifth Street, NW and Aspen Street, NW

The intersection of Fifth Street and Aspen Street, NW is unsignalized and controlled by All-Way STOP signs. Aspen Street, NW is a bidirectional collector road oriented in the east-west direction. It has on-street permitted parking on both sides and a posted speed limit of 25 mph. The width of the segment is approximately 29 feet (curb to curb).

Fifth Street, NW and Whittier Street, NW

The intersection of Fifth Street and Whittier Street, NW is unsignalized and controlled by All-Way STOP signs. Whittier Street is a bidirectional local roadway with one lane per direction and an east-west orientation. Whittier Street has a posted speed limit of 25 mph and is approximately 30 feet wide (curb to curb) with residential on-street parking on both sides.

Fifth Street, NW and Van Buren Street, NW

The intersection of Fifth Street and Van Buren Street, NW is signalized. Van Buren Street is a bidirectional local road with one lane per direction and an east-west orientation. The posted speed limit is 25 mph and is approximately 30 feet wide (curb to curb) with residential on-street parking on both sides.

North Dakota Avenue, NW between Sheridan Street and Peabody Street, NW

The study segment consists of four intersections located in a residential area in the northwest quadrant of the District of Columbia. The main segment, North Dakota Avenue, NW is a bidirectional road oriented in the northwest-southeast direction and is classified as a local roadway according to DC's Functional Classification Map. It has on-street permitted parking on both sides and a posted speed limit of 25 mph. The length and width of the segment are approximately 1,845 feet and 40 feet (curb to curb), respectively. The following intersections are located within the segment.

North Dakota Avenue and Sheridan Street, NW

North Dakota Avenue and Sheridan Street, NW is a signalized intersection. Sheridan Street, NW is a local roadway with an east-west orientation and one lane per direction. The segment has on-street parking on both sides and is approximately 30 feet wide (curb to curb) with a posted speed limit of 25 mph.

North Dakota Avenue and Rittenhouse Street, NW

The intersection of North Dakota Avenue and Rittenhouse Street, NW is controlled by All-Way STOP signs. Rittenhouse Street, NW is a local roadway with an east-west orientation and one lane per direction. The width of the segment is approximately 30 feet wide (curb to curb), and on-street parking is permitted on both sides. The posted speed limit is 25 mph.

North Dakota Avenue and Quackenbos Street, NW

The intersection of North Dakota Avenue and Quackenbos Street, NW is controlled by All-Way STOP signs. Quackenbos Street, NW is a bidirectional local road that runs in the east-west direction and has one lane per direction. There is on-street parking permitted on both sides. The width of the segment is approximately 30 feet wide (curb to curb) with a posted speed limit of 25 MPH.

North Dakota Avenue and Peabody Street, NW

The intersection of North Dakota Avenue and Peabody Street, NW is signalized. Peabody Street, NW is a local road with an east-west orientation and one lane per direction. There is on-street parking permitted on both sides and a posted speed limit of 25 mph. The width of the segment is approximately 30 feet wide (curb to curb).

Sargent Road, NE between South Dakota Avenue and Varnum Street, NE

This segment consists of five intersections located in the northeast quadrant of the District of Columbia. The main segment, Sargent Road, NE is a bidirectional minor arterial street which runs in the north-south orientation and has permitted on-street parking on the right side of the northbound approach. The length and width of the street are approximately 1,450 feet and 29 feet (curb to curb), respectively. The segment is located in a residential area with a hospital, school and parks nearby. The following intersections are located within the segments.

Sargent Road and South Dakota Avenue, NE

The intersection of Sargent Road and South Dakota Avenue, NE is signalized. South Dakota Avenue, NE is a bidirectional principal arterial road with a southeast-northwest orientation and two lanes per direction. It is approximately 43 feet wide (curb to curb) with restricted parking on both sides and a posted speed limit of 25 mph.

Sargent Road and Buchanan Street, NE

Sargent Road and Buchanan Street, NE is controlled by All-Way STOP signs. Buchanan Street, NE is a bidirectional collector street oriented in an east-west direction with one lane per direction. It is approximately 29 feet wide (curb to curb) and has residential parking on both sides. The posted speed limit is 25 mph.

Sargent Road and Allison Street, NE

The intersection of Sargent Road and Allison Street, NE is controlled by All-Way STOP signs. Allison Street, NE is a bidirectional local road oriented in an east-west orientation with one lane per direction. It is approximately 29 feet wide (curb to curb) and has residential parking on both sides. Allison Street has a statutory speed limit of 25 mph.

Thirteenth Street and Varnum Street, NE

The intersection of Thirteenth Street and Varnum Street, NE is signalized. Varnum Street, NE is a bidirectional local road with an east-west direction. Varnum Street is approximately 29 feet wide (curb to curb) with residential parking on both sides. The posted school-zone speed limit is 15 mph.

Twentieth Street, NE between Monroe Street and Rhode Island Avenue, NE

The study segment consists of five intersections located in a residential area in the northeast quadrant of the District of Columbia. The main segment, Twentieth Street, NE is a bidirectional collector street with a north-south orientation. Twentieth Street, NE has one lane per direction with residential parking on both sides of the segment. It has on-street permitted parking on both sides and a posted speed limit of 25 mph. The segment are 1,475 feet long and 30 feet wide (curb to curb). The following intersections are located within this segment.

Twentieth Street and Monroe Street, NE

The intersection of Twentieth Street and Monroe Street, NE is signalized. Monroe Street, NE is a minor arterial road that is oriented in the east-west direction and has one lane per direction. There is residential parking on the right side of the eastbound approach. The width of the street is approximately 29 feet (curb to curb) with a posted speed limit of 25 mph.

Twentieth Street and Lawrence Street, NE

The intersection of Twentieth Street and Lawrence Street, NE is controlled by All-Way STOP signs. Lawrence Street, NE is a bidirectional local road with one lane per direction. It has an east-west orientation and is 30 feet wide (curb to curb) with residential parking on both sides and a posted speed limit of 25 mph.

Twentieth Street and Kearny Street, NE

The intersection of Twentieth Street and Kearny Street, NE is controlled by All-Way STOP signs. Kearny Street, NE is a bidirectional local road with one lane per direction and an east-west orientation. Kearny Street is 30 feet wide (curb to curb) with residential parking on both sides and a posted speed limit of 25 mph.

Twentieth Street and Jackson Street, NE

Twentieth Street and Jackson Street, NE is unsignalized and controlled by All-Way STOP signs. Jackson Street is a bidirectional local road with an east-west orientation. It is 30 feet wide (curb to curb) with residential parking on both sides and a posted speed limit of 25 mph.

Twentieth Street and Rhode Island Avenue, NE

The intersection of Twentieth Street and Rhode Island Avenue, NE is signalized. Rhode Island Avenue, NE is a bidirectional minor arterial with three lanes per direction and is oriented in the east-west direction. The road is approximately 70 feet wide (curb to curb) and has permitted parking on both sides. The posted speed limit on Rhode Island Avenue, NW is 30 mph.

Third Street, NE between Florida Avenue and K Street, NE

The study segment consists of four intersections located in the northeast quadrant of the District of Columbia. The main segment, Third Street, NE, is a bidirectional street oriented in the north-south direction and is classified as a local roadway according to DC's Functional Classification Map. Third Street, NE has on-street parking permitted on both sides and a posted speed limit of 25 mph. The segment is approximately 1,915 feet long and 32 feet wide (curb to curb). The segment is located in a residential area with a few small businesses, a storage facility, retail and parking lots. The intersections located within this segment are the following.

Third Street and Florida Avenue, NE

The T-intersection of Third Street and Florida Avenue, NE is signalized. Florida Avenue is a bidirectional principal arterial roadway with three lanes per direction and an east-west orientation. The posted speed limit is 25 mph, and the road is approximately 69 feet wide (curb to curb) with restricted parking on both sides.

Third Street and M Street, NE

The intersection of Third Street and M Street, NE is unsignalized and controlled by All-Way STOP signs. M Street, NE is a bidirectional collector road with an east-west orientation and one lane per direction. M Street is approximately 30 feet wide (curb to curb) with on-street permitted parking only on one side of the east leg of the intersection.

Third Street and L Street, NE

The intersection of Third Street and L Street, NE is controlled by All-Way STOP signs. L Street, NE is a bidirectional local road with an east-west orientation. It has one lane per direction and is approximately 30 feet wide (curb to curb), with on-street parking on both sides of the road.

Third Street and K Street, NE

The intersection of Third Street and K Street, NE is signalized. K Street is a bidirectional minor arterial road with one lane per direction and an east-west orientation. K Street has on-street parking on both sides and is approximately 40 feet wide (curb to curb) with a posted speed limit of 25 mph.

Fifth Street, NE between Florida Avenue and K Street, NE

This segment consists of four intersections located in the northeast quadrant of the District of Columbia. The main segment, Fifth Street, NE, is a bidirectional street oriented in the north-south direction and is classified as a local roadway according to DC's Functional Classification Map. Fifth Street, NE has on-street permitted parking on both sides and a posted speed limit of 25 mph. The segment is approximately 1,500 feet long and 30 feet wide (curb to curb). The segment is located in a residential area with a few business offices and a school. The intersections located within the segment are the following.

Fifth Street and Florida Avenue, NE

The intersection of Fifth Street and Florida Avenue, NE is signalized. Florida Avenue is a bidirectional principal arterial roadway with three lanes per direction. It is oriented in the east-west direction and has a posted speed limit of 25 mph. The width of the segment is approximately 69 feet (curb to curb).

Fifth Street and M Street, NE

The intersection of Fifth Street and M Street, NE is controlled by All-Way STOP signs. M Street, NE is a one-way collector road oriented in the eastbound direction with on-street permitted parking on both sides. The width of the segment is approximately 32 feet (curb to curb) with a posted speed limit of 25 mph.

Fifth Street and L Street, NE

The intersection of Fifth Street and L Street, NE is controlled by All-Way STOP signs. L Street, NE is a bidirectional local road with one lane per direction, and it is oriented in the east-west direction. It has on-street parking on both sides of the road and is approximately 32 feet wide (curb to curb) with a posted speed limit of 25 mph.

Fifth Street and K Street, NE

The intersection of Fifth Street and K Street, NE is signalized. K Street, NE is a bidirectional minor arterial with one lane per direction and an east-west orientation. It has on-street parking on both sides and is approximately 40 feet wide (curb to curb) with a posted school-zone speed limit of 15 mph.

Sixth Street, NE between Florida Avenue and K Street, NE

The study segment consists of four intersections located in the northeast quadrant of the District of Columbia. The main segment, Sixth Street, NE, is a bidirectional street oriented in the north-south direction and is classified as a collector roadway according to DC's Functional Classification Map. Sixth Street, NE has a bicycle lane and on-street permitted parking on both sides with a posted speed limit of 25 mph. The segment is approximately 1,370 feet long and 45 feet wide (curb to curb). It is located in a residential area with retail, religious places of worship and a school. The following intersections are located within this segment.

Sixth Street and M Street, NE

The intersection of Sixth Street and M Street, NE is signalized. M Street NE is a one-way collector road oriented in the eastbound direction with on-street permitted parking on both sides. The width of the segment is approximately 32 feet (curb to curb) and has a posted speed limit of 25 mph.

Sixth Street and Orleans Place, NE

The T-intersection of Sixth Street and Orleans Place, NE is controlled by All-Way STOP signs. Orleans Place, NE is a one-way local road, oriented in the westbound direction, with on-street parking on both sides of the road. The width of the segment is approximately 24 feet (curb to curb) with a posted speed limit of 25 mph.

Sixth Street and L Street, NE

The intersection of Sixth Street and L Street, NE is controlled by All-Way STOP signs. L Street, NE is a bidirectional local road with one lane per direction and an east-west orientation. It has on-street parking on both sides of the road and is approximately 32 feet wide (curb to curb), with a posted speed limit of 25 mph.

Sixth Street and K Street, NE

The intersection of Sixth Street and K Street, NE is signalized. K Street is a bidirectional minor arterial road oriented in the east-west direction. The road has one lane per direction and designated on-street parking on both sides. It is approximately 40 feet wide (curb to curb), with a posted speed limit of 25 mph.

Seventh Street, NE between Florida Avenue and K Street, NE

The study segment consists of four intersections located in the northeast quadrant of the District of Columbia. The main segment, Seventh Street, NE, is a bidirectional local roadway oriented in the north-south direction. Seventh Street, NE has on-street permitted parking on both sides and a posted speed limit of 25 mph. The segment is located in a residential area with a few schools, shops and offices. The length and width of the corridor are approximately 1,020 feet and 30 feet (curb to curb), respectively. The following intersections are located within the segment.

Seventh Street and Florida Avenue, NE

The intersection of Seventh Street and Florida Avenue, NE is signalized. Florida Avenue, NE is a bidirectional major arterial roadway with three lanes per direction and a northwest-southeast orientation. The road is approximately 55 feet wide (curb to curb) with a posted speed limit of 25 mph. On-street parking is not permitted.

Seventh Street and Morton Place, NE

The T-intersection of Seventh Street and Morton Place, NE is controlled by All-Way STOP signs. Morton Place, NE is classified as a one-way local roadway with a posted speed limit of 25 mph and on-street parking on both sides. Morton Place, NE runs in the eastbound direction and is approximately 24 feet wide (curb to curb).

Seventh Street and L Street, NE

The intersection of Seventh Street and L Street, NE is controlled by All-Way STOP signs. L Street, NE is a bidirectional local roadway with one lane per direction and an east-west orientation. It is approximately 32 feet wide (curb to curb) with on-street parking on both sides and a posted speed limit of 25 mph.

Seventh Street and K Street, NE

Seventh Street and K Street, NE is controlled by a traffic signal. K Street, NE is a bidirectional minor arterial roadway with a posted speed limit of 25 mph. It has on-street permitted parking on both sides and is approximately 40 feet wide (curb to curb).

Eleventh Street, NE between Maryland Avenue and C Street, NE

This segment consists of four intersections located in a residential area in the northwest quadrant of the District of Columbia. The main segment, Eleventh Street, NE, is a bidirectional collector road oriented in the north-south direction. Eleventh Street, NE has on-street permitted parking on both sides and a posted speed limit of 25 mph. The length and width of the corridor are approximately 1,180 feet and 32 feet (curb to curb), respectively. The following intersections are located within the segment.

Eleventh Street and Maryland Avenue, NE

The intersection of Eleventh Street and Maryland Avenue, NE is controlled by a traffic signal. Maryland Avenue, NE is a bidirectional minor arterial road with a posted speed limit of 25 MPH and on-street parking on both sides. Maryland Avenue, NE has two lanes per direction with a northeast-southwest orientation and is approximately 65 feet wide (curb to curb).

Eleventh Street and E Street, NE

The intersection of Eleventh Street and E Street, NE is controlled by All-Way STOP signs. E Street, NE is a bidirectional local street with one lane per direction and an east-west orientation. E Street, NE is approximately 30 feet wide (curb to curb) with on-street parking on both sides and a posted speed limit of 25 mph.

Eleventh Street and D Street, NE

The intersection of Eleventh Street and D Street, NE is controlled by All-Way STOP signs. D Street, NE is a one-way local road with a posted speed limit of 25 mph and on-street parking on both sides. D Street, NE runs in the eastbound direction and is approximately 34 feet wide (curb to curb).

Eleventh Street and C Street, NE

The intersection of Eleventh Street and C Street, NE is signalized. C Street, NW is a one-way minor arterial roadway with a posted speed limit of 25 mph. It has a bike lane on one side and designated on-street parking on both sides of the street. It runs in the westbound direction and is approximately 34 feet wide (curb to curb).

Thirteenth Street, NE between Maryland Avenue and C Street, NE

This segment consists of five intersections located in the northeast quadrant of the District of Columbia. The main segment, Thirteenth Street, NE, is a bidirectional collector street which runs in the north-south orientation with on-street parking on both sides. The length and width of the street are approximately 1,670 feet and 32 feet (curb to curb), respectively. The segment is located in a residential area with a few markets, coffee shops, restaurants and schools nearby. The following intersections are located within the segment.

Thirteenth Street and Maryland Avenue, NE

The intersection of Thirteenth Street and Maryland Avenue, NE is signalized. Maryland Avenue, NE has a northeast-southwest orientation with two lanes per direction and on-street parking on both sides. It is classified as a minor arterial and is 58 feet wide (curb to curb). The posted speed limit is 25 mph.

Thirteenth Street and F Street, NE

The intersection of Thirteenth Street and F Street, NE is controlled by All-Way STOP signs. F Street, NE is a bidirectional local road with one lane per direction, and it runs in the east-west direction. The eastbound approach of F Street is a one-way road, while the westbound approach is a bidirectional road. It is approximately 34 feet wide (curb to curb) and has residential parking on both sides. The posted school zone speed limit is 15 mph.

Thirteenth Street and E Street, NE

The intersection of Thirteenth Street and E Street, NE is an All-Way STOP Control. E Street, NE is a bidirectional (one lane per direction) local road with an east-west orientation. It is approximately 30 feet wide (curb to curb) and has residential parking on both sides. E Street, NE has a statutory speed limit of 25 mph.

Thirteenth Street and D Street, NE

The intersection of Thirteenth Street and D Street, NE is controlled by All-Way STOP signs. D Street, NE is a bidirectional local road that is oriented in the east-west direction and has one lane per direction. The eastbound approach is one-way, while the westbound approach is bidirectional. It is approximately 33 feet wide (curb to curb) and has residential parking on both sides. D Street, NE has a statutory speed limit of 25 mph.

Thirteenth Street and C Street, NE

The intersection of Thirteenth Street and C Street, NE is signalized. C Street, NE is a westbound one-way minor arterial road with one lane. There are dedicated residential parking lanes on both sides of C Street, NE and a bicycle lane on the right side of the traveling lane. C Street, NE is approximately 30 feet wide (curb to curb) with a statutory speed limit of 25 mph.

Fourteenth Street, NE between Maryland Avenue and C Street, NE

The study segment consists of five intersections located in the northeast quadrant of the District of Columbia. The main segment, Fourteenth Street, NE, is a one-way collector street oriented in the southbound direction with dedicated residential parking on both sides. There is a bicycle lane on the right side of the southbound approach and a posted speed limit of 25 mph. The segment is located in a residential area with a few retail and coffee shops, a park, and a few schools nearby. The length and width of the street are approximately 2,080 feet and 31 feet (curb to curb), respectively. The following intersections are located within the segment.

Fourteenth Street and Maryland Avenue, NE

The intersection of Fourteenth Street and Maryland Avenue, NE is signalized. Maryland Avenue, NE has a northeast-southwest orientation with two lanes per direction and on-street parking on both sides of the street. Maryland Avenue NE is a minor arterial with a posted speed limit of 25 mph and is approximately 58 feet wide (curb to curb).

Fourteenth Street and F Street, NE

The intersection of Fourteenth Street and F Street, NE is controlled by All-Way STOP signs. F Street, NE is a bidirectional local road with one lane per direction that runs in the east-west direction. It is approximately 34 feet wide (curb to curb) and has residential parking on both sides of the street. Also, there is a posted school-zone speed limit of 15 mph.

Fourteenth Street and E Street, NE

The intersection of Fourteenth Street and E Street, NE is controlled by All-Way STOP signs. E Street, NE is a bidirectional local road with one lane per direction and an east-west orientation. E Street NE is approximately 30 feet wide (curb to curb) and has residential parking on both sides of the street with a statutory speed limit of 25 mph.

Fourteenth Street and D Street, NE

The intersection of Fourteenth Street and D Street, NE is controlled by All-Way STOP signs. D Street, NE is a bidirectional local road that is oriented in the east-west direction with one lane per direction. It is approximately 33 feet wide (curb to curb) and has residential parking on both sides. D Street, NE has a statutory speed limit of 25 mph.

Fourteenth Street and C Street, NE

The intersection of Fourteenth Street and C Street, NE is signalized. C Street, NE is a westbound one-way minor arterial road with one lane. There are dedicated residential parking lanes on both sides of C Street, NE and a bicycle lane on the right side of the traveling lane. C Street, NE is approximately 30 feet wide (curb to curb), and there is a statutory speed limit of 25 mph.

Ninth Street, SE between East Capitol Street and Independence Avenue, SE

The study segment consists of three intersections located in the southeast quadrant of the District of Columbia. The main segment, Ninth Street, SE, is a bidirectional local street that is oriented in the north-south direction. Ninth Street, NE has on-street permitted parking on both sides and a posted speed limit of 25 mph. The segment is located in a residential area with a police station and hair salon at the corner of E Capitol Street, SE. The length and width of the street are approximately 800 feet and 30 feet (curb to curb), respectively. The following intersections are located within this segment.

Ninth Street and East Capitol Street, SE

The intersection of Ninth Street and East Capitol Street, SE is controlled by a traffic signal. East Capitol Street, SE is classified as a collector roadway with a posted speed limit of 25 mph. It has a dedicated bicycle lane and on-street parking on both sides. East Capitol Street, SE is a bidirectional street with one lane per direction and an east-west orientation. The road is approximately 45 feet wide (curb to curb).

Ninth Street and North Carolina Avenue, SE

The intersection of Ninth Street and North Carolina Avenue, SE is controlled by All-Way STOP signs. North Carolina Avenue, SE is a bidirectional collector road with one lane per direction and a posted speed limit of 25 mph. It is oriented in the northeast-southwest direction and has dedicated bicycle lanes and on-street parking on both sides. The road is approximately 54 feet wide (curb to curb).

Ninth Street and Independence Avenue, SE

The intersection of Ninth Street and Independence Avenue, SE is controlled by a traffic signal. Independence Avenue, SE is classified as a major arterial roadway with a posted speed limit of 25 mph and has on-street parking on both sides. Independence Avenue, SE is a one-way street that runs in the eastbound direction. The road is approximately 32 feet wide (curb to curb).

G Street, SE between Eighth Street and Eleventh Street, SE

The study segment consists of four intersections located in a residential area in the southeast quadrant of the District of Columbia. The main segment, G Street, SE, is a bidirectional local road oriented in the east-west direction. It has on-street permitted parking on both sides and a posted speed limit of 25 mph. The length and width of the corridor are approximately 970 feet and 32 feet (curb to curb), respectively. The following intersections are located within the segment.

G Street and Eighth Street, SE

The intersection of G Street and Eighth Street, SE is signalized. Eighth Street is a bidirectional minor arterial oriented in the north-south direction. It has one lane per direction and on-street parking on both sides of the street. The segment is approximately 50 feet wide (curb to curb) and has a posted speed limit of 25 mph. Right turns are restricted on red signals.

G Street and Ninth Street, SE

The intersection of G Street and Ninth Street, SE is controlled by All-Way STOP signs. Ninth Street SE is a local road that is oriented in the north-south direction. The southbound approach of 9th Street, SE is bidirectional with one lane per direction and on-street parking on both sides. The northbound approach is a one-way road in the southbound direction. The width of the segment is approximately 30 feet (curb to curb).

G Street and Tenth Street, SE

The intersection of G Street and Tenth Street, SE is controlled by All-Way STOP signs. Tenth Street, SE is a bidirectional local road with one lane per direction and it is oriented in the north-south direction. The southbound approach of 10th Street, SE has on-street parking on both sides of the street, whereas the northbound approach is a one-way street oriented in the southbound direction. The width of the segment is approximately 30 feet (curb to curb).

G Street and Eleventh Street, SE

The intersection of G Street and Eleventh Street, SE is signalized. Eleventh Street is a bidirectional minor arterial oriented in the north-south direction. It has one lane per direction and on-street parking on both sides. Both the southbound and northbound approaches have two receiving lanes of which one is a left turn storage lane. Both approaches have bicycle lanes located in between the travel lanes and the parking lanes. The width of the segment is approximately 55 feet (curb to curb).

DATA COLLECTION

Field data collection was conducted at the 30 selected segments on typical weekdays (Tuesday, Wednesday and Thursday) from April 2017 through December 2017. The data collection schedule was organized to achieve a robust sample, where the research team conducted the data collection at every intersection within each segment of study in a day. In the event that road maintenance or construction was ongoing at any of the intersections, the data collection was deferred until it was completed. The following data associated with intersection traffic operations were obtained:

A. Vehicular and Pedestrian Volumes

Video recording cameras were installed at every intersection within each segment of study. All cameras for a segment were installed at the same time. The video recordings took place on typical weekdays (Tuesday, Wednesday and Thursday) over a 12-hour duration from 6:30 a.m.to 6:30 p.m. The volumes were then extracted from video playbacks employing Turning Movement Counting Boxes. From the data, the a.m. and p.m. peak hour volumes, peak hour factors and heavy vehicle percentages were calculated using the JAMAR PetraPRO™ software. Figures 3 and 4 present a picture showing one of the video cameras mounted at one of the intersections of study and the equipment used for the study, respectively.

Figure 3. Traffic Recording Camera Installed at Intersection of Study

Figure 4. Traffic Recording Camera and Turning Movement Counting Box

B. STOP Sign Compliance at AWSC Intersections

From the videos, observations were made at the AWSC intersections within the segments that were in close proximity to the upstream or downstream signalized intersections. Vehicular compliance at the STOP sign was observed during the off-peak period from 10:00AM to 1:00PM and was classified as either compliant or noncompliant. A vehicle was in compliance if it came to a complete stop at the STOP bar for at least one second before proceeding through the intersection. On the other hand, a vehicle was not in compliance if it did not come to a complete stop before entering the intersection.

Guidelines were given to data collection technicians to ensure consistency in observations. In addition, a data collection sheet was created to keep records of compliance observations. Prior to commencement of the actual data collection effort, several preliminary runs were conducted to familiarize the team with the data collection process. In all, 13,956 observations were made at 57 AWSC intersections, after which the data was entered into Microsoft Excel™ and IBM SPSS™ for analysis. Vehicles' compliance data collection sheet is presented in Appendix A.

C. Signal Timing Data

Signal timing data for the signalized intersections located within the selected segments was obtained from the District Department of Transportation (DDOT). For those intersections where data was not available, signal timing was measured in the field. During field measurements, the green, change and clearance timing intervals for each phase at the intersection were measured three times, after which the averages of these measurements were computed. The cycle lengths, which are the sum of the average green and yellow intervals times, were also computed. The sample data collection sheet used during field measurements is presented in Appendix B.

D. Geometric Characteristics

Geometric features of the segments were obtained through field measurements and observations during the field assessment. The following characteristics were documented.

- Number of lanes
- Lane widths
- Link (segment) lengths
- Presence of on-street parking
- Presence of left turn restrictions
- Presence of Right Turn on Red restrictions
- Intersection approach grades
- Land Use

DATA ANALYSIS

A compliance rate (CR) analysis and a LOS analysis were conducted to obtain parameters for further statistical analyses. Figure 5 presents a picture of one of the Howard University Transportation Research and Traffic Safety Data Center (HUTRC) team members conducting data analysis.

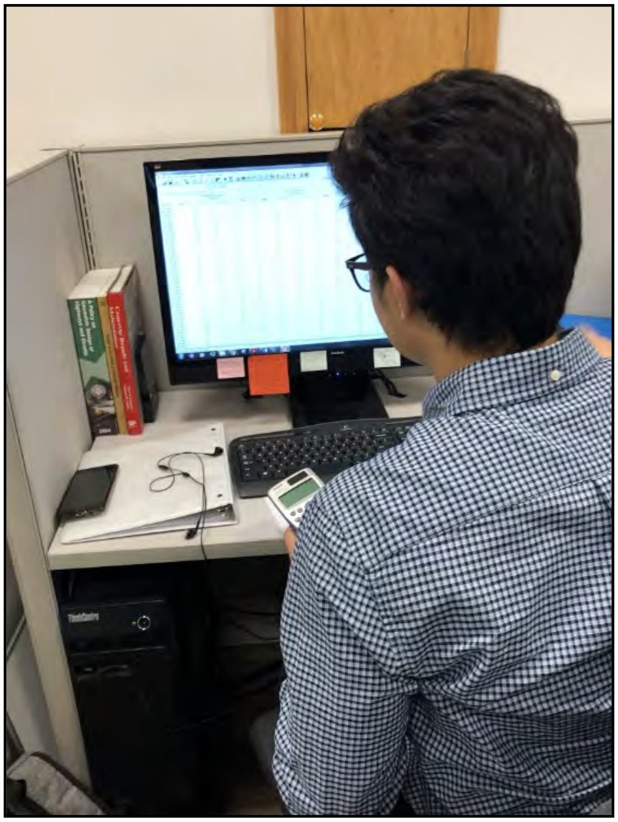


Figure 5. Data Analysis Process

Compliance Rate (CR)

The CR for each of the selected AWSC intersections that were in close proximity to the upstream or downstream signalized intersections was computed using the following equation in Microsoft EXCEL™:

$$\text{Compliance Rate} = \frac{\text{VC}}{\text{TV}} \text{ X } 100$$

where:

VC = Number of vehicles in compliance, i.e., those that stopped before proceeding through the intersection, and

TV = Total number of vehicles going through the intersection on the same approach

Level of Service (LOS)

The existing conditions data was used as input in Synchro 9™ software program to simulate the “before” scenario. In the “after” scenario, the AWSC intersections in each segment were signalized (and optimized), while maintaining the same conditions at the signalized intersections. The resulting intersections’ LOS, as well as the segments’ MOEs for both scenarios, were extracted for comparison. The two main MOEs used to assess the performance of the segments for the “before” and “after” scenarios were control delay and average travel speed. These were defined as follows:

i. Control Delay: Control delay is the summation of uniform delay, incremental delay and initial delay with respect to a progression factor. Control delay includes movements at slower speeds and stops on intersection approaches as vehicles move up in queue position or slow down upstream of an intersection.

ii. Average Travel Speed: This is the average speed of vehicles on the segments. This speed is computed taking into consideration the intersections’ spacing, the running time between intersections, and the control delay of vehicles at each intersection. Hence, the resulting estimated speeds may not correspond to speed measurements made from end-to-end travel time runs that measure a small subset of the possible origin-destination combinations along a segment.

The results of the analysis from Synchro 9™ software program are attached as Appendix C.

Statistical and Regression Analyses

Statistical Analysis

Descriptive statistics such as the mean, median, and standard deviation were computed for the CR and the segments’ MOEs which were extracted from the Synchro 9™ outputs and were used for further evaluation.

Model Development

To determine whether there exists a relationship between the distance between an AWSC intersection and an upstream or downstream signalized intersection, and the compliance rate (CR), a nonlinear regression model was determined to assume the following form:

$$CR = k_0 + \mathrm{k}_1 \mathrm{e}^{\mathrm{k}_2\,\mathrm{D}} + \varepsilon$$

where:

CR = Compliance Rate (%).

D = Distance between signalized and AWSC intersections (ft.)

CR is the dependent variable and *D* is the independent variable. In addition, k_0 is the regression constant and k_1 and k_2 are the regression coefficients with an associated error of ε [$\varepsilon \sim N(0, \sigma^2)$]. The form of the regression model (nonlinear) was based on several transformations since the data was determined not to follow the normal distribution. A scatter plot of CR and D showed no issue with heteroscedasticity (see Appendix D).

Test of Hypothesis

The test statistic primarily used in this study for the comparison is that of the mean. The hypothesis that the "after" scenario would improve mobility along the segment over the "before" scenario was tested at 5% level of significance. The hypothesized improvements in the "after" scenario are as follows:

- reduced mean control delay along the segments, and
- increased mean travel speed along the segments

A. Reduced Control Delays

It is hypothesized that the "after" scenario would result in reduced control delays along the segments. This can be mathematically written as:

$H_0: \bar{X}_2 \geq \bar{X}_1$

$H_1: \bar{X}_2 < \bar{X}_1$

where,

$\bar{X}_1$ = mean control delay in the "before" scenario

$\bar{X}_2$ = mean control delay in the "after" scenario

B. Increased Average Travel Speed

It is also hypothesized that the "after" scenario would result in increased travel speeds along the segments. This can be mathematically written as:

$H_0: \bar{Y}_2 \leq \bar{Y}_1$

$H_1: \bar{Y}_2 > \bar{Y}_1$

where,

$\bar{Y}_1$ = mean travel speed in the "before" scenario

$\bar{Y}_2$ = mean travel speed in the "after" scenario

The t-test was used to test for statistical significance of the reduction in control delays and increase in travel speeds (if any). The data of both MOEs were assumed to follow the normal distribution (as per the Central Limit Theorem, large sample sizes of N≥30 are assumed to be normally distributed.) The t-test determines the significance of the mean difference in control delays and travel speeds using the following equations:

$$T = \frac{\bar{d}}{SE\ (\bar{d})}$$, and

$$\bar{d} = \overline{(m_1 - m_2)}$$

where,

T = t-statistic

$\bar{d}$ = mean difference in MOE

$SE\ (\bar{d})$ = standard error of differences

m_1 = MOE at “before” scenario

m_2 = MOE at “after” scenario

The statistical analyses were conducted using SPSS and Microsoft Excel™.

V. RESULTS

COMPLIANCE RATES

The observed number of vehicles that complied with the STOP sign at the selected AWSC intersections and the corresponding computed CR are presented in Table 5.

Table 5. Summary of STOP Sign Compliance per Intersection

#	Segments	Unsignalized Intersection	Distance to Signalized. Intersection (ft.)	# of Vehicles Traveling to the Signal	# of Vehicles in Compliance	Compliance Rate (%)
1	Albemarle St. NW	Albemarle St. NW and 38th St. NW (EB)	502	405	252	62.22
		Albemarle St. NW and 38th St. NW (WB)	446	395	285	72.15
2	Van Ness St. NW	Van Ness St. NW and 38th St. NW	662	635	567	89.37
		Van Ness St. NW and 37th St. NW	873	469	433	92.27
3	Macomb St. NW	Macomb St. NW and 36th St. NW	420	165	91	55.00
		Macomb St. NW and 35th St. NW	642	194	161	83.00
4	Woodley Rd. NW	Woodley Rd NW and 36th St. NW	488	205	148	72.00
		Woodley Rd NW and 35th St. NW	620	241	195	81.00
5	S St. NW	S St. NW and New Hampshire Ave. NW	570	116	92	79.17
		S St. NW and 17th St. NW	560	354	219	62.00
6	O St. NW	O St. NW and 12th St. NW (EB)	275	95	62	65.00
		O St. NW and 12th St. NW (WB)	411	95	59	62.00
7	T St. NW	T St. NW and 11th St. NW	226	357	206	57.63
8	11th St. NE	11th St. NW and W St. NW	565	256	179	70.00
		11th St. NW and V St. NW	382	379	254	67.02
9	13th St. NW	13th St. NW and Fairmont St. NW	361	908	545	60.00
		13th St. NW and Girard St. NW	363	738	483	65.48
10	Fairmont St. NW	Fairmont St. NW and 13th St. NW	712	96	84	88.00
		Fairmont St. NW and 11th St. NW	392	94	64	67.92
11	Warder St. NW	Warder St. NW and Newton Pl NW	271	593	347	58.59
12	Taylor St. NW	Taylor St. NW and Kansas Ave. NW	425	195	119	61.00
		Taylor St. NW and 13th St. NW	857	121	110	91.00
13	Upshur St. NW	Upshur St. NW and 7th St. NW	408	449	323	72.00
		Upshur St. NW and 8th St. NW	496	358	274	76.45
14	Decatur St. NW	Decatur St. NW and Piney Branch Rd NW	281	36	21	58.80
		Decatur St. NW and 15th Street NW	430	30	20	65.00
15	13th St. NW	13th St. NW and Madison St. NW	653	488	420	86.11
		13th St. NW and Longfellow St. NW	383	663	418	63.00

#	Segments	Unsignalized Intersection	Distance to Signalized. Intersection (ft.)	# of Vehicles Traveling to the Signal	# of Vehicles in Compliance	Compliance Rate (%)
16	Sheridan St. NW	Sheridan St. NW and 9th St. NW	445	92	69	75.00
		Sheridan St. NW and 7th St. NW	716	82	74	90.13
17	Aspen St. NW	Aspen St. NW and 6th St. NW	604	173	133	77.00
		Aspen St. NW and 4th St. NW	488	310	211	68.00
18	5th St. NW	5th St. NW and Whittier St. NW	500	174	120	69.00
		5th St. NW and Butternut St. NW	440	110	80	73.00
19	N. Dakota Ave. NW	N. Dakota Ave. NW and Rittenhouse St. NW	618	30	23	75.00
		N. Dakota Ave. NW and Quackenbos St. NW	565	116	86	74.00
20	13th St. NE	Sargent Rd. NE and Buchanan St. NE	142	462	273	59.00
		Sargent Rd. NE and Allison St. NE	885	381	343	90.00
21	20th St. NE	20th St. NE and Lawrence St. NE	295	134	78	58.00
		20th St. NE and Jackson St. NE	305	149	94	63.17
22	3rd St. NE	3rd St. NE and M St. NE	757	133	117	88.00
		3rd St. NE and L St. NE	440	86	53	62.00
23	5th St. NE	5th St. NE and M St. NE	373	159	105	66.12
		5th St. NE and L St. NE	439	44	29	67.00
24	6th St. NE	6th St. NE and L St. NE	440	401	281	70.00
		6th St. NE and Orleans Pl. NE	243	873	510	58.39
25	7th St. NE	7th St. NE and L St. NE	436	102	66	65.00
		7th St. and Morton Pl. NE	300	53	37	69.00
26	11th St. NE	11th St. NE and E St. NE	232	59	32	55.00
		11th St. NE and D St. NE	433	320	195	61.00
27	13th St. NE	13th St. NE and F St. NE	285	361	220	61.00
		13th St. NE and D St. NE	443	82	57	70.00
28	14th St. NE	14th St. NE and D St. NE	355	307	175	57.00
29	9th St. SE	9th St. SE and N. Carolina Ave. SE (NB)	520	97	78	80.00
		9th St. SE and N. Carolina Ave. SE (SB)	300	93	59	63.04
30	G St. SE	G St. SE and 9th St. SE	328	120	78	64.65
		G St. SE and 10th St. SE	310	123	78	63.78

RESULTS OF LOS ANALYSIS

Level of Service (LOS) analysis was conducted based on procedures in the 2016 Highway Capacity Manual (HCM), using the Synchro 9™ software program. The LOS of each AWSC intersection was assessed for both the "before" and "after" scenarios. However, the LOS of the signalized intersections was assessed for only the "before" scenario, since the conditions at those intersections were kept the same in the "after" scenario. Also, the segments' MOEs (control delay and average travel time) were obtained from the Synchro 9™ outputs. Summaries of the results are presented in Tables 6 through 8. Table 6 shows the LOS for the signalized intersections. The LOS for the "before" and "after" scenarios of the AWSC intersections are shown in Table 7. The Segment MOEs are presented in Table 8. A screen capture of the analysis in Synchro 9™ is presented in Figure 6 with the detailed results of the analyses attached as Appendix C.

Table 6. Summary of Control Delay and LOS per Signalized Intersection

			AM		PM	
#	Main St.	Signalized Intersection	Control Delay	LOS	Control Delay	LOS
1	Albemarle St. NW	Albemarle St. NW and Nebraska Ave. NW	19	B	21	C
		Albemarle St. NW and Reno Rd. NW	23	C	30	C
2	Van Ness St. NW	Van Ness St. NW and Wisconsin Ave. NW	24	C	28	C
		Van Ness St. NW and Reno Rd. NW	37	D	32	C
3	Macomb St. NW	Macomb St. NW and Wisconsin Ave. NW	16	B	18	B
		Macomb St. NW and 34th St. NW	23	C	19	B
4	Woodley Rd. NW	Woodley Rd. NW and Wisconsin Ave. NW	21	C	19	B
		Woodley Rd. NW and 34th St. NW	38	D	22	C
5	S St. NW	S St. NW and 18th St. NW	15	B	133	F
		S St. NW and 16th St. NW	75	E	48	D
6	O St. NW	O St. NW and 11th St. NW	17	B	14	B
		O St. NW and 13th St. NW	18	B	17	B
7	T St. NW	T St. NW and 13th St. NW	16	B	122	F
		T St. NW and Vermont Ave. NW	14	B	16	B
8	11th St. NE	11th St. NE and Maryland Ave. NE	12	B	81	F
		11th St. NE and C St. NE	59	E	13	B
9	13th St. NW	13th St. NW and Euclid St. NW	14	B	19	B
		13th St. NW and Harvard St. NW	18	B	21	C
10	Fairmont St. NW	Fairmont St. NW and 14th St. NW	11	A	9	A
		Fairmont St. NW and Sherman St. NW	19	B	24	C
11	Warder St. NW	Warder St. NW and Kenyon St. NW	321	F	244	F
		Warder St. NW and Otis Pl. NW	16	B	32	C
12	Taylor St. NW	Taylor St. NW and Georgia Ave. NW	55	E	28	D
		Taylor St. NW and 14th St. NW	21	C	20	C
13	Upshur St. NW	Upshur St. NW and New Hampshire Ave. NW	38	D	31	C
		Upshur St. NW and 9th St, NW	1	A	1	A
14	Decatur St. NW	Decatur St. NW and 16th St. NW	10	B	16	B
		Decatur St. NW and 14th St. NW	18	B	21	B

#	Main St.	Signalized Intersection	AM Control Delay	AM LOS	PM Control Delay	PM LOS
15	13th St. NW	13th St. NW and Colorado Ave. NW	19	B	25	C
		13th St. NW and Kennedy St. NW	27	C	25	C
16	Sheridan St. NW	Sheridan St. NW and Georgia Ave. NW	31	C	32	C
		Sheridan St. NW and 5th St. NW	10	B	10	B
17	Aspen St. NW	Aspen St. NW and Piney Branch Rd. NW	38	C	34	B
		Aspen St. NW and Blair Rd. NW	42	D	21	C
18	5th St. NW	5th St. NW and Van Buren St. NW	11	B	9	A
		5th St. NW and Cedar St. NW	128	F	9	A
19	N. Dakota Avenue NW	N. Dakota Ave. NW and Sheridan St. NW	27	C	31	C
		N. Dakota Ave. NW and Peabody St. NW	9	A	16	B
20	13th Street NE	Sargent Rd. NE and S. Dakota Ave. NE	16	C	14	B
		13th St. NE and Varnum St. NE	25	C	14	B
21	20th St. NE	20th St. NE and Monroe St. NE	12	B	12	B
		20th St. NE and Rhode Island Ave. NE	60	D	19	C
22	3rd St. NE	3rd St. NE and Florida Ave. NE	6	A	17	B
		3rd St. NE and K St. NE	15	B	23	C
23	5th St. NE	5th St. NE and Florida Ave. NE	16	B	14	B
		5th St. NE and K St. NE	25	C	26	C
24	6th St. NE	6th St. NE and K St. NE	20	B	41	F
		6th St. NE and M St. NE	13	B	18	B
25	7th Street NE	7th St. NE and K St. NE	40	D	107	A
		7th St. NE and Florida Ave. NE	9	A	12	A
26	11th St. NE	11th St. NE and Maryland Ave. NE	12	B	81	F
		11th St. NE and C St. NE	59	E	13	B
27	13th St. NE	13th St. NE and Maryland Ave. NE	110	F	44	D
		13th St. NE and C St. NE	47	D	10	B
28	14th St. NE	14th St. NE and Maryland Ave. NE	142	F	43	D
		14th St. NE and C St. NE	35	D	12	B
29	9th St. SE	9th St. SE and Independence Ave. SE	10	B	16	B
		9th St. SE and E Capitol St. SE	12	B	12	B
30	G St. SE	G St. SE and 8th St. SE	12	B	16	B
		G St. SE and 11th St. SE	31	C	20	C

Table 7. Summary of Control Delay (CD) and LOS per Unsignalized Intersection

#	Segment	Intersections	AM				PM			
			Before		After		Before		After	
			CD	LOS	CD	LOS	CD	LOS	CD	LOS
1	Albemarle St. NW	Albemarle St. NW and 38th St. NW	12	B	11	B	54	F	24	C
2	Van Ness St. NW	Van Ness St. NW and 38th St. NW	12	B	8	A	13	B	6	A
		Van Ness St. NW and 37th St. NW	18	C	10	A	22	C	15	B
3	Macomb St. NW	Macomb St. NW and 36th St. NW	11	A	8	A	9	A	7	A
		Macomb St. NW and 35th St. NW	10	B	8	A	9	A	8	A
4	Woodley Rd. NW	Woodley Rd. NW and 36th St. NW	13	B	10	A	10	A	14	B
		Woodley Rd. NW and 35th St. NW	14	B	12	B	12	B	11	B
5	S St. NW	S St. NW and New Hampshire Ave. NW	29	D	13	B	14	B	13	B
		S St. NW and 17th St. NW	17	C	13	B	13	B	11	B
6	O St. NW	O St. NW and 12th St. NW	10	A	11	B	14	B	13	B
7	T St. NW	T St. NW and 12th St. NW	22	C	12	B	60	F	22	C
		T St. NW and 11th St. NW	15	B	12	B	21	C	17	B
8	11th St. NE	11th St. NW and W St. NW	15	B	10	B	14	B	9	A
		11th St. NW and V St. NW	13	B	10	B	12	B	10	B
9	13th St. NW	13th St. NW and Fairmont St. NW	40	E	15	B	40	E	10	B
		13th St. NW and Girard St. NW	40	E	12	B	31	D	7	A
10	Fairmont St. NW	Fairmont St. NW and 13th St. NW	82	F	16	C	25	C	12	B
		Fairmont St. NW and 11th St. NW	28	D	14	B	35	D	13	B
11	Warder St. NW	Warder St. NW and Lamont St. NW	13	B	9	A	23	C	9	A
		Warder St. NW and Park Rd. NW	14	B	8	A	25	C	10	B
		Warder St. NW and Newton Pl. NW	10	A	4	A	15	B	4	A
12	Taylor St. NW	Taylor St. NW and Kansas Ave. NW	26	D	13	B	13	B	11	B
		Taylor St. NW and 13th St. NW	34	D	12	B	24	C	12	B
13	Upshur St. NW	Upshur St. NW and 7th St. NW	11	B	8	A	14	B	13	B
		Upshur St. NW and 8th St. NW	13	B	14	B	20	C	11	B
14	Decatur St. NW	Decatur St. NW and Piney Branch Rd. NW	7	A	8	A	7	A	8	A
		Decatur St. NW and 15th St. NW	7	A	7	A	7	A	7	A
15	13th St. NW	13th St. NW and Madison St. NW	16	C	10	A	35	D	26	C
		13th St. NW and Longfellow St. NW	15	B	8	A	24	C	26	C
16	Sheridan St. NW	Sheridan St. NW and 9th St. NW	8	A	8	A	9	A	9	A
		Sheridan St. NW and 8th St. NW	8	A	7	A	8	A	7	A
		Sheridan St. NW and 7th St. NW	8	A	8	A	8	A	7	A
17	Aspen St. NW	Aspen St. NW and 6th St. NW	10	A	11	B	9	A	11	B
		Aspen St. NW and 5th St. NW	17	C	15	B	12	B	9	A
		Aspen St. NW and 4th St. NW	11	B	12	B	11	B	9	A
18	5th St. NW	5th St. NW and Whittier St. NW	14	B	14	B	14	B	11	B
		5th St. NW and Aspen St. NW	14	B	12	B	13	B	11	B
		5th St. NW and Butternut St. NW	15	B	13	B	11	B	9	A
19	N. Dakota Ave. NW	N. Dakota Ave. NW and Rittenhouse St. NW	8	A	7	A	8	A	8	A
		N. Dakota Ave. NW and Quackenbos St. NW	9	A	10	A	9	A	10	A

#	Segment	Intersections	AM Before CD	AM Before LOS	AM After CD	AM After LOS	PM Before CD	PM Before LOS	PM After CD	PM After LOS
20	13th St. NE	Sargent Rd. NE and Buchanan St. NE	17	C	9	A	13	B	9	A
		Sargent Rd. NE and Allison St. NE	18	C	12	B	16	C	16	C
21	20th St. NE	20th St. NE and Lawrence St. NE	8	A	8	A	8	A	9	A
		20th St. NE and Kearny St. NE	8	A	5	A	8	A	4	A
		20th St. NE and Jackson St. NE	8	A	8	A	9	A	7	A
22	3rd St. NE	3rd St. NE and M St. NE	9	A	11	B	146	F	24	C
		3rd St. NE and L St. NE	13	B	12	B	17	C	14	B
23	5th St. NE	5th St. NE and M St. NE	10	A	9	A	11	B	12	B
		5th St. NE and L St. NE	17	B	15	B	11	B	11	B
24	6th St. NE	6th St. NE and L St. NE	18	C	11	B	29	D	16	C
		6th St. NE and Orleans Pl. NE	10	B	4	A	15	C	4	A
25	7th St. NE	7th St. NE and L St. NE	9	A	8	A	11	B	11	B
		7th St. NE and Morton Pl. NE	7	A	8	A	8	A	5	A
26	11th St. NE	11th St. NE and E St. NE	9	A	9	A	9	A	4	A
		11th St. NE and D St. NE	9	A	9	A	13	B	13	B
27	13th St. NE	13th St. NE and F St. NE	10	A	7	A	8	A	9	A
		13th St. NE and E St. NE	14	B	9	A	8	A	6	A
		13th St. NE and D St. NE	10	A	10	A	11	B	14	B
28	14th St. NE	14th St. NE and F St. NE	9	A	10	A	9	A	10	A
		14th St. NE and E St. NE	8	A	6	A	9	A	5	A
		14th St. NE and D St. NE	10	A	9	A	12	B	10	A
29	9th St. SE	9th St. SE and N. Carolina Ave. SE (NB)	11	B	10	A	13	B	13	B
30	G St. SE	G St. SE and 9th St. SE	10	A	9	A	11	A	10	A
		G St. SE and 10th St. SE	9	A	9	A	10	A	7	A

Table 8. Summary of Before and After Control Delay and Average Travel Speed per Segment

#	Segment	AM Before CD	AM Before Avg. Speed	AM After Optimized CD	AM After Optimized Avg. Speed	PM Before CD	PM Before Avg. Speed	PM After Optimized CD	PM After Optimized Avg. Speed
1	Albemarle Street NW	20	7	19	7	32	4	24	5
2	Van Ness Street NW	26	5	25	5	27	4	25	5
3	Macomb Street NW	17	9	16	9	17	9	17	9
4	Woodley Road NW	25	7	24	8	18	9	18	9
5	S Street NW	43	4	39	5	56	4	55	4
6	O Street NW	16	10	16	10	15	11	15	11
7	T Street NW	17	7	13	8	62	3	103	3
8	Eleventh Street NE	34	6	33	6	27	7	26	7
9	Thirteenth Street NW	27	5	15	7	27	4	14	7

		AM				PM			
		Before		After		Before		After	
#	Segment	CD	Avg. Speed	Optimized CD	Optimized Avg. Speed	CD	Avg. Speed	Optimized CD	Optimized Avg. Speed
10	Fairmont Street NW	32	6	15	10	23	8	15	10
11	Warder Street NW	133	2	130	2	98	3	91	3
12	Taylor Street NW	38	5	31	5	23	7	20	7
13	Upshur Street NW	23	5	22	5	22	5	20	5
14	Decatur Street NW	13	9	13	9	17	9	17	9
15	Thirteenth Street NW	20	9	16	11	27	8	25	8
16	Sheridan Street NW	23	5	23	5	23	5	22	4
17	Aspen Street NW	30	7	30	7	21	9	21	9
18	Fifth Street NW	44	1	43	1	11	4	10	4
19	North Dakota Avenue NW	15	7	15	7	18	7	18	6
20	Thirteenth Street NE	18	6	15	7	14	7	13	7
21	Twentieth Street NE	40	8	39	8	15	13	14	13
22	Third Street NE	11	11	11	10	43	4	20	6
23	Fifth Street NE	18	7	17	8	17	7	17	7
24	Sixth Street NE	16	8	13	10	28	5	21	6
25	Seventh Street NE	17	9	17	10	42	5	41	6
26	Eleventh Street NE	26	6	12	10	43	4	19	8
27	Thirteenth Street NE	57	3	55	2	24	5	24	5
28	Fourteenth Street NE	69	3	69	3	22	7	21	7
29	Ninth Street SE	11	12	11	13	14	11	13	11
30	G Street SE	20	6	20	6	16	7	15	7

Figure 6. Synchro 9™ Analysis Screen Capture

The following conclusion can be drawn from the results.

- The LOS for the “after” scenario for the AWSC intersections showed improvements over the “before” scenario.

- The segment average travel speed in the “after” scenario remained the same or increased compared to the “before” scenario.

STATISTICAL ANALYSIS

The summaries of the descriptive statistical analyses for the CR and the segment MOEs (control delays and average travel speed) are presented in the following sections. The reported descriptive statistics are the mean, median, standard deviation and 95% confidence interval. The detailed results of the descriptive statistics are attached as Appendix D.

Descriptive Statistics for Compliance Rate

This section provides the summary of the descriptive statistics for CR and distance between successive signalized and unsignalized intersections located within the selected segments of study. The summary of the descriptive statistics is presented in Table 9. From the table, it can be observed that the mean compliance rate was 69.84%, with a standard deviation of 10.53 %. The highest and lowest observed compliance rates were 92.27% and 55.00% respectively. Also, the mean distance between consecutive signalized and unsignalized intersections was 461.15 feet with a standard deviation of 169.82 feet. The highest and lowest distances measured were 885 feet and 142 feet respectively.

Table 9. Summary of Descriptive Statistics for STOP Sign Compliance

	Descriptive Statistics					
					95% Confidence Interval	
Variable	**Mean**	**Standard Deviation**	**Lowest Value**	**Highest Value**	**Lower Bound**	**Upper Bound**
Compliance Rate (%)	69.84	10.53	55.00	92.27	66.99	72.68
Distance (ft.) to Signalized Intersection	461.15	169.82	142.00	885.00	415.24	507.05

Descriptive Statistics for Segment MOEs

Tables 10 and 11 present the summary of the descriptive statistics of the segments’ control delays and average travel speeds respectively, for the a.m. and p.m. peak periods. Table 10 shows that the mean control delays for the 30 segments were higher for the “before” scenario than the “after” scenario. For the a.m. peak period, the mean control delay was 29.93 sec/veh with a standard deviation of 23.72 sec/veh. However, this reduced to 27.23 sec/veh with a corresponding standard deviation of 23.77 sec/veh for the “after” scenario. During the p.m. peak period, the mean control delay was 28.80 sec/veh with a standard deviation of 18.05 sec/veh. Likewise, this was reduced to 23.80 sec/veh with a corresponding standard deviation of 16.39 sec/veh for the “after” scenario. The highest control delay of 133 sec/veh occurred during the a.m. peak, while the lowest control delay of 10 sec/veh occurred during the p.m. peak period for the “after” scenario. Figure 7 compares the mean control delays during the a.m. and p.m. peak periods. It is observed in the figure that during both peak periods the mean control delays were higher for the “before” scenario than the “after” scenario.

Table 10. Summary of Descriptive Statistics for Control Delay

		Descriptive Statistics						
							95% Confidence Interval	
Peak Period	MOE	Mean	Standard Deviation	Median	Min. Value	Max. Value	Lower Bound	Upper Bound
A.M.	“Before” Control Delay (sec/veh)	29.93	23.72	23.00	11	133	21.08	38.79
	“After” Control Delay (sec/veh)	27.23	23.77	18.00	11	130	18.36	36.11
P.M.	“Before” Delay (sec/veh)	28.07	18.05	23.00	11	98	21.33	34.81
	“After” Control Delay (sec/veh)	23.80	16.39	19.50	10	91	17.68	29.92

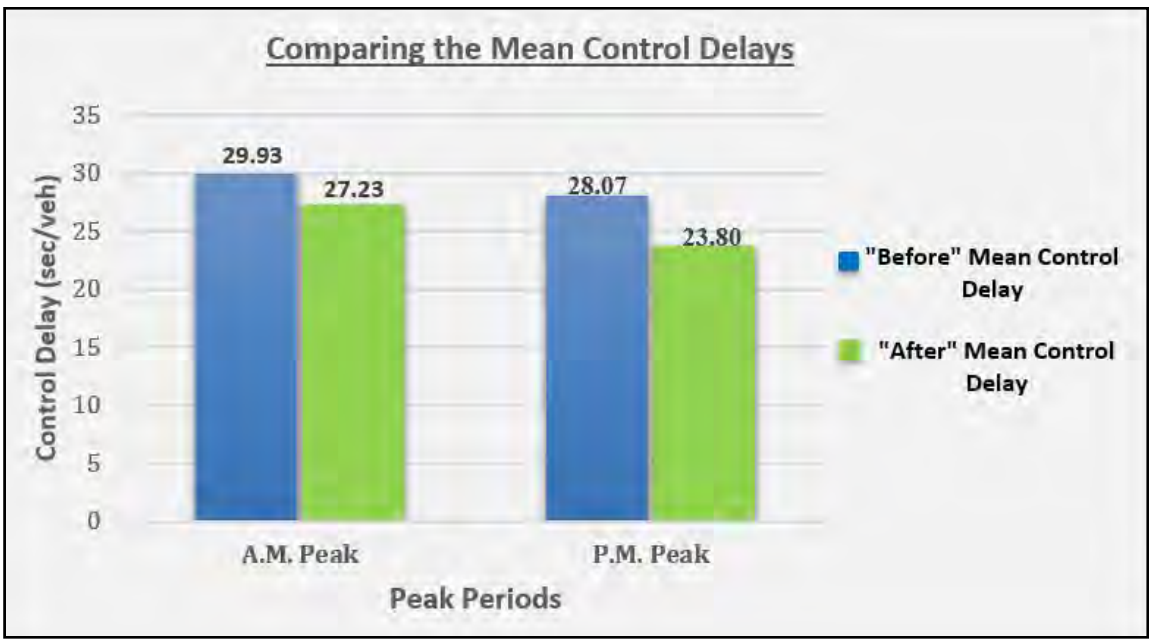


Figure 7. Mean Control Delays for the A.M. and P.M. Peaks

Table 11 shows the summary of the descriptive statistics of the average travel speeds on the segments. It is observed from the table that the mean average travel speeds were lower for the “before” scenario than the “after” scenario. During the a.m. peak period, the mean average travel speed was 6.5 mph with a standard deviation of 2.54 mph. However, this increased to 7.13 mph with a corresponding standard deviation of 2.89 mph for the “after” scenario. During the p.m. peak period the mean average travel speed was 6.53 mph with a standard deviation of 2.58 mph. Similarly, this increased to 6.93 mph with a corresponding standard deviation of 2.45 mph in the “after” scenario. The highest average segment speed of 13 mph occurred during the p.m. peak, while the lowest average segment speed of 1 mph occurred during the a.m. peak period of the “before” scenario. A comparison of the mean average travel speeds is shown in Figure 8. The figure shows that during both peak periods the mean average travel speeds were lower for the “before” scenario than for the “after” scenario.

Table 11. Summary of Descriptive Statistics for Average Segment Travel Speed

		Statistic						
							95% Confidence Interval	
Peak Period	MOE	Mean	Standard Deviation	Median	Min. Value	Max. Value	Lower Bound	Upper Bound
A.M.	“Before” Average Travel Speed (mph)	6.50	2.54	6.50	1	12	5.55	7.45
	“After” Average Travel Speed (mph)	7.13	2.89	7.00	1	13	6.06	8.21
P.M.	“Before” Average Travel Speed (mph)	6.50	2.58	7.00	3	13	5.54	7.46
	“After” Average Travel Speed (mph)	6.93	2.45	7.00	3	13	6.02	7.85

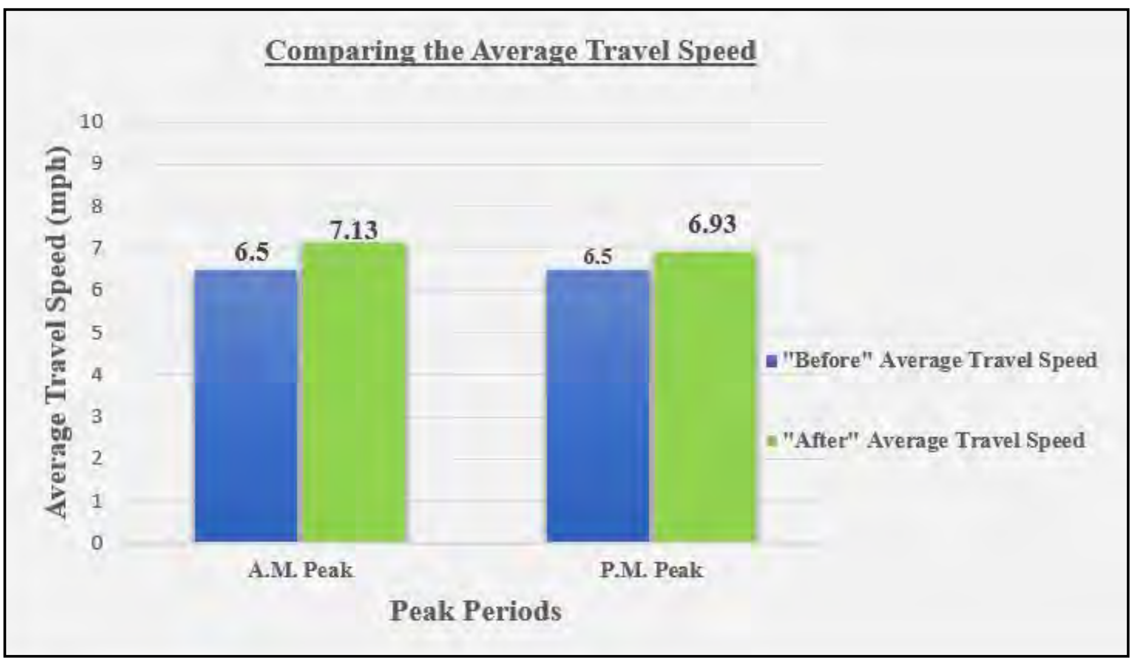


Figure 8. Mean Average Travel Speed for the A.M. and P.M. Peaks

Regression Analysis

A regression analysis was conducted to determine the relationship between the distance between an AWSC intersection and signalized intersection and the CR. A non-linear regression model was then developed to predict the CR based on the distance. The model was assumed to take the form:

$$CR = k_0 + k_1 e^{k_2 D} + \varepsilon$$

The summary of the regression analysis is presented in Tables 12 and 13. The detailed results of the regression analysis are presented in Appendix D.

The results in Table 12 show the estimates of the regression coefficients. The coefficients k_0, k_1 and k_2 were estimated to be 99.99, -66.90 and -0.002 respectively. The R^2 value of 0.738 shown in Table 13 also indicates that the model explains a high percentage (73.8%) of the variance in the data.

Table 12. Regression Coefficients

			95% Confidence Interval	
Parameter	**Estimate**	**Std. Error**	**Lower Bound**	**Upper Bound**
K_0	99.990	13.776	72.345	127.635
K_1	-66.900	8.102	-83.158	-50.642
K_2	-.002	.001	-.004	-6.161E-5

Table 13. ANOVA Results

Source	Sum of Squares	df	Mean Squares
Regression	272,673.183	3	90,891.061
Residual	1,565.600	52	30.108
Uncorrected Total	274,238.783	55	
Corrected Total	5,983.953	54	
Dependent variable: Compliance Rate			
R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .738.			

The regression model was therefore determined to be:

$$CR = 99.99 - 66.907e^{-0.002\,D}$$

Regression Model Test

Residual Plots

For a statistically significant regression model, the residuals would approximate the random errors that establish the relationship between the explanatory variables and the response variables. Therefore, if the residuals appear to behave randomly, it suggests that the model fits the data well. Figure 9 depicts the residual plots for the regression model. The plot shows evenly distributed random plots, which confirm that the model fits the data sets well. Thus, from the figure, it can be concluded that the model adequately predicts compliance rate based on the distance between the intersections.

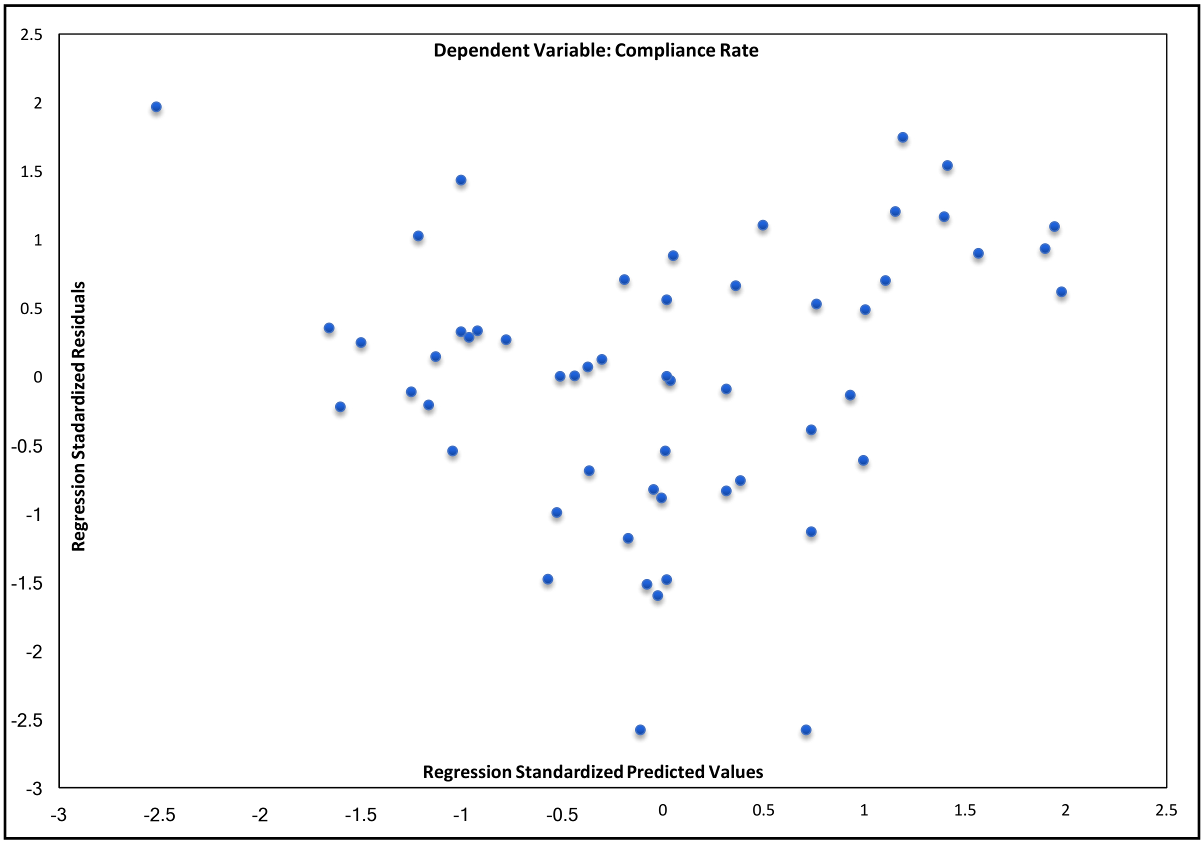


Figure 9. Residual Plot for Compliance Rate

Mean Absolute Percentage Error

The Mean Absolute Percentage Error (MAPE) is a measure of the quality of a regression model. MAPE indicates how much error is made in the predicted values as compared to the observed values. It is calculated by dividing the absolute errors of the predicted values by the observed values, and then averaging the obtained percentages. Thus;

$$\text{MAPE} = \frac{1}{n}\sum\frac{|A - P|}{A} \times 100$$

where,

A = Observed values

P = Predicted values

n = Number of observations

The MAPE analysis was performed using observed CR and predicted CR values from the regression model. Details of the analysis are presented in Appendix D. The analysis resulted in a MAPE of 6.1%. This indicates that the regression model predicts CR with a 6.1% margin of error.

Results of Test for Hypothesis

The results of the t-test conducted to test for statistically significant differences in the mean "before" and "after" segments' MOEs are presented in the following sections.

T-Test for Differences in Segments' Control Delays for the "Before" and "After" Scenarios

Table 14 presents the results of the t-test to test for statistically significant differences in the control delays of the "before" and "after" scenarios. Separate analyses were conducted for the a.m. and p.m. peak periods. It can be observed from the table that during the a.m. peak period the mean difference in control delays of the "before" and "after" scenarios was 2.70 sec/v. This difference was determined to be statistically significant at a 5% level of significance, t_{29} = 3.407 and p = 0.002. The p.m. peak period results also show that there was a statistically significant difference in the mean difference in control delays of the "before" and "after" scenarios, t_{29} = 3.515 and p = 0.001.

Table 14. T-Test Results – Control Delay

Paired Samples T-Test									
		Paired Differences							
					95% Conf. Int. of the Difference				
Peak Period	Variables	Mean Diff.	Std. Dev.	Std. Error Mean	Lower	Upper	t	df	Sig.
A.M.	"Before" Control Delay – "After" Control Delay	2.700	4.340	0.792	1.079	4.321	3.407	29	.002
P.M.	"Before" Control Delay – "After" Control Delay	4.267	6.648	1.214	1.784	6.749	3.515	29	.001

T-Test for Differences in Segments' Average Travel Speeds for the "Before" and "After" Scenarios

Statistical significant differences in the "before" and "after" average travel speeds (mph) on the segments was tested for using a t-test. The results are presented in Table 15. It can be observed from the table that during the a.m. peak period the mean difference in average travel speed was -6.33 mph. This difference was determined to be significant, t_{29} = -2.92 and p = 0.007. In addition, the p.m. peak period results show that there was significant difference in mean difference of average travel speed (-0.433 mph), t_{29} = -2.21 and p = 0.035.

Table 15. T-Test Results – Average Travel Speed

Paired Samples Test									
		Paired Differences							
					95% Conf. Int. of the Difference				
Peak Period	Variables	Mean Diff.	Std. Dev.	Std. Error Mean	Lower	Upper	t	df	Sig.
A.M.	"Before" Average Travel Speed – "After" Average Travel Speed	-0.633	1.19	-0.22	-1.077	-0.190	-2.92	29	.007
P.M.	"Before" Average Travel Speed – "After" Average Travel Speed	-0.433	1.07	0.20	-0.834	-0.033	-2.21	29	.035

VI. DISCUSSION OF RESULTS

Two main analyses were conducted: a LOS analysis and a statistical analysis. The results of the LOS analysis showed that, generally, the control delays at the AWSC intersections reduced in the "after" scenario. The statistical analysis was comprised of a regression analysis and a test of hypotheses. The regression analysis investigated the relationship between CR at AWSC intersections and the distance between the intersections and adjacent signalized intersections. Generally, CR increased as distance between the intersections and adjacent signalized intersections increased. The developed nonlinear regression model explained 73.8% of the variance in the data. Additionally, the model predicts CR with a 6.1% margin of error. Based on the model, to achieve a minimum compliance rate of 95%, a minimum distance of approximately 1,298 ft. between intersections is required.

The tests of hypotheses were conducted using a t-test. Firstly, it was hypothesized that there is a statistically significant reduction in the segments' control delays for the "after" scenario. Secondly, it was hypothesized that there is a statistically significant increase in the segments' average travel speeds for the "after" scenario. The results of the t-test for the first hypothesis showed a (statistically significant at 95% confidence interval) reduction in the segments' mean control delay with p-values of 0.002 and 0.001 for the a.m. and p.m. peak periods, respectively. These results show that lower delays are expected on the segments when conditions are similar to the "after" scenario.

Similarly, the average travel speeds through the segments were generally increased in the "after" scenario. The results of the t-test showed that the increase in average travel speeds was statistically significant at 5% level of significance for both the a.m. and p.m. peak periods, with p values of 0.007 and 0.035, respectively.

VII. CONCLUSIONS AND RECOMMENDATIONS

The study revealed that there exists a positive relationship between the CR at AWSC intersections that are adjacent to signalized intersections and the distance between the two intersections. Higher CR were observed at AWSC intersections with longer distances to the next signalized intersection. In addition, the proposed regression model has a high explanatory power on the observed data. The model can therefore accurately predict the CR at AWSC intersections based on the distance between the AWSC and adjacent signalized intersections.

The MOEs (control delay and average travel speed) of the segments significantly improved for the "after" scenario. Statistically significant reductions in control delays were reported, while average travel speeds significantly increased, at 5% level of significance. Hence, mobility through the segments improved significantly for the "after" scenario. The research revealed that even though some unsignalized intersections may not meet the MUTCD warrants for signalization, signalizing and coordinating them with existing signalized intersections improves mobility and throughput.

The study was based on data collected on 30 segments in the District of Columbia and could be adopted for similar urban jurisdictions. Longer segments with multiple AWSCs and signalized intersections could be considered. In addition, models could be developed for segments with different functional classifications.

APPENDIX A:
VEHICLE COMPLIANCE DATA COLLECTION SHEET

STOP Compliance Data Sheet

Name: AY	Date: 1/8/2018	Direction: WB
Location: 38th and Albermarle		Segment: Albermarle St, NW

Interval		Total
10:00 - 11:00 AM		85
11:00 – 12:00 PM		93
12:00 – 1:00 PM		107

Name: AT	Date: 1/8/2018	Direction: EB
Location: 38th and Albermarle		Segment: Albermarle St, NW

Interval		Total
10:00 - 11:00 AM		80
11:00 – 12:00 PM		83
12:00 – 1:00 PM		89

STOP Compliance Data Sheet

Name: AY | Date: 12th Oct, 2017 | Direction: WB

Location: Van Ness & 38th | Segment: Van Ness Street, NW

Interval		Total
10:00 - 11:00 AM		195
11:00 – 12:00 PM		191
12:00 – 1:00 PM		181

Name: BABIN | Date: 12th Oct 2017 | Direction: EB

Location: Van Ness & 37th St. NW | Segment: Van Ness St NW.

Interval		Total
10:00 - 11:00 AM		133
11:00 – 12:00 PM		160
12:00 – 1:00 PM		141

STOP Compliance Data Sheet

Name: AY | Date: 10-03-17 | Direction: EB

Location: Macomb & 35th, NW | Segment: Macomb Street, NW.

Interval		Total
10:00 - 11:00 AM		56
11:00 – 12:00 PM		49
12:00 – 1:00 PM		57

Name: Mel | Date: 10-03-2017 | Direction: WB

Location: Macomb street & 36th St, Nw. | Segment: Macomb Street, NW.

Interval		Total
10:00 - 11:00 AM		26
11:00 – 12:00 PM		39
12:00 – 1:00 PM		26.

STOP Compliance Data Sheet

Name: BABIN	Date: 12-Oct-2017	Direction: WB
Location: Woodley St & 36th Street NW	Segment: Woodley Street, NW	

Interval		Total
10:00 - 11:00 AM		47
11:00 – 12:00 PM		39
12:00 – 1:00 PM		62

Name: Babin	Date: 12-Oct-2017	Direction: EB
Location: Woodley St & 35th St. NW	Segment: Woodley Street, NW	

Interval		Total
10:00 - 11:00 AM		56
11:00 – 12:00 PM		59
12:00 – 1:00 PM		80

STOP Compliance Data Sheet

Name: AY | Date: 11/2/2017 | Direction: WB

Location: S Street & New Hampshire, NW | Segment: S Street, NW.

Interval		Total
10:00 - 11:00 AM	卌 卌 卌 卌 卌, 卌 卌 |	36
11:00 – 12:00 PM	卌 卌 卌 卌 卌 卌	30
12:00 – 1:00 PM	卌 卌 卌 卌 卌 |	26

Name: Mel | Date: 11/2/2017 | Direction: EB

Location: S Street & 17th Street, NW | Segment: S Street, NW.

Interval		Total
10:00 - 11:00 AM	卌 卌 卌 卌 卌, 卌 卌 卌 卌 卌, 卌 卌	60
11:00 – 12:00 PM	卌 卌 卌 卌 卌, 卌 卌 卌 卌 卌, 卌 卌 卌 卌	70
12:00 – 1:00 PM	卌 卌 卌 卌 卌, 卌 卌 卌 卌 卌, 卌 卌 卌 卌 卌||, 卌 卌 ||||	89

STOP Compliance Data Sheet

Name: Babin | Date: 1/10/2017 | Direction: EB

Location: 12th St & O St, NW | Segment: O St, NW

Interval		Total
10:00 - 11:00 AM	卌 卌 卌 卌 ||||	24
11:00 – 12:00 PM	卌 卌 卌 |	16
12:00 – 1:00 PM	卌 卌 卌 卌 ||	22

Name: Babin | Date: 1/10/2017 | Direction: WB

Location: 12th St & O St, NW | Segment: O St, NW

Interval		Total
10:00 - 11:00 AM	卌 卌 卌 卌 卌 ||||	29
11:00 – 12:00 PM	卌 卌 ||	12
12:00 – 1:00 PM	卌 卌 卌 |||	18

STOP Compliance Data Sheet

Name: Shawn Daniel	Date: 11/02/2017	Direction: EB
Location: T & 11th Street, NW	Segment: T Street, NW	
Interval		Total
10:00 - 11:00 AM		64
11:00 – 12:00 PM		72
12:00 – 1:00 PM		69

Name:	Date:	Direction:
Location:	Segment:	
Interval		Total
10:00 - 11:00 AM		
11:00 – 12:00 PM		
12:00 – 1:00 PM		

STOP Compliance Data Sheet

Name: Ay	Date: 11/02/2017	Direction: NB
Location: 11th St & W Street, NW		Segment: 11th Street, NW.

Interval		Total
10:00 - 11:00 AM	卌 卌 卌 卌 卌, 卌 卌 卌 卌 卌. 卌	55
11:00 – 12:00 PM	卌 卌 卌 卌 卌, 卌 卌 卌 卌 卌, 卌 卌 卌 |	66
12:00 – 1:00 PM	卌 卌卌 卌 卌. |卌 卌 卌 卌 卌, 卌 |||	58

Name: Mel	Date: 11/02/2017	Direction: SB
Location: 11th Street & V Street, NW		Segment: 11th Street, NW

Interval		Total
10:00 - 11:00 AM	卌 卌 卌 卌 卌, 卌 卌 卌 卌-卌, 卌 卌	60
11:00 – 12:00 PM	卌 卌 卌 卌 卌, 卌 卌 卌 卌 卌, 卌 卌 卌 卌 卌, 卌 卌 |||	68
12:00 – 1:00 PM	卌卌 卌 卌 卌, 卌 卌 卌 卌 卌, 卌 卌 卌 卌 卌, 卌 卌 卌 卌, |||	98

STOP Compliance Data Sheet

Name: Travis	Date: 6/29/2017	Direction: NB
Location: 13th St & Girard Street, NW	Segment: 13th Street, NW	

Interval		Total
10:00 - 11:00 AM		196
11:00 – 12:00 PM		163
12:00 – 1:00 PM		125

Name: Carlos	Date: 6/29/2017	Direction: SB
Location: 13th St & Fairmont St. NW	Segment: 13th St. NW	

Interval		Total
10:00 - 11:00 AM		118
11:00 – 12:00 PM		170
12:00 – 1:00 PM		257

STOP Compliance Data Sheet

Name: BOLU	Date: 12/12/2017	Direction: WB
Location: Fairmont Street & 13th Street		Segment: Fairmont Street.

Interval		Total
10:00 - 11:00 AM	HHH HHH HHH HHH I	21
11:00 – 12:00 PM	HHH HHH HHH HHH HHH HHH	29
12:00 – 1:00 PM	HHH HHH HHH HHH HHH HHH IIII	34

Name: BOLU	Date: 12/12/2017	Direction:
Location: Fairmont Street & 11th Street		Segment: Fairmont Street

Interval		Total
10:00 - 11:00 AM	HHH HHH IIII	14
11:00 – 12:00 PM	HHH HHH HHH III	18
12:00 – 1:00 PM	HHH HHH HHH HHH HHH HHH II	32

STOP Compliance Data Sheet

Name: Carlos	Date: 6/9/17	Direction: NB
Location: Warder St & Newton Pl, NW	Segment: Warder St. NW	

Interval		Total
10:00 - 11:00 AM		110
11:00 – 12:00 PM		116
12:00 – 1:00 PM		122

Name:	Date:	Direction:
Location:	Segment:	

Interval		Total
10:00 - 11:00 AM		
11:00 – 12:00 PM		
12:00 – 1:00 PM		

STOP Compliance Data Sheet

Name: Babin | Date: 1/5/2018 | Direction: EB

Location: Taylor & Kansas Ave, NW. | Segment: Taylor Street, NW.

Interval		Total
10:00 - 11:00 AM	~~IIII~~ ~~IIII~~ ~~IIII~~ ~~IIII~~ ~~IIII~~, ~~IIII~~ ~~IIII~~ III	38
11:00 – 12:00 PM	~~IIII~~ ~~IIII~~ ~~IIII~~ ~~IIII~~ ~~IIII~~, ~~IIII~~ ~~IIII~~ III	38
12:00 – 1:00 PM	~~IIII~~ ~~IIII~~ ~~IIII~~ ~~IIII~~ ~~IIII~~, ~~IIII~~ ~~IIII~~ ~~IIII~~ III	43

Name: Babin | Date: 1/5/2018 | Direction: WB

Location: Taylor & 13th St. NW | Segment: Taylor Street, NW.

Interval		Total
10:00 - 11:00 AM	~~IIII~~ ~~IIII~~ ~~IIII~~ ~~IIII~~ ~~IIII~~ III	28
11:00 – 12:00 PM	~~IIII~~ ~~IIII~~ ~~IIII~~ ~~IIII~~ ~~IIII~~, ~~IIII~~ ~~IIII~~ ~~IIII~~ IIII	44
12:00 – 1:00 PM	~~IIII~~ ~~IIII~~ ~~IIII~~ ~~IIII~~ ~~IIII~~, ~~IIII~~ ~~IIII~~ III	38

STOP Compliance Data Sheet

Name: BOLU | Date: 1/23/2018 | Direction: WB

Location: Upshur St & 8th St, NW | Segment: Upshur St, NW

Interval		Total
10:00 - 11:00 AM		90
11:00 – 12:00 PM		100
12:00 – 1:00 PM		84

Name: MEL | Date: 1/23/2018 | Direction: EB

Location: UPSHUR ST & 7th ST, NW | Segment: UPSHUR ST, NW

Interval		Total
10:00 - 11:00 AM		117
11:00 – 12:00 PM		110
12:00 – 1:00 PM		96

STOP Compliance Data Sheet

Name: Carlos	Date: 6/15/17	Direction: EB
Location: Decatur St & 15th St. NW		Segment: Decatur St, NW

Interval		Total
10:00 - 11:00 AM	𝍸 I	6
11:00 – 12:00 PM	𝍸 II	7
12:00 – 1:00 PM	𝍸 II	7

Name: Babin	Date: 6/15/17	Direction: WB
Location: Decatur St & Piney Branch Road.		Segment: Decatur St. NW

Interval		Total
10:00 - 11:00 AM	𝍸 II	7
11:00 – 12:00 PM	𝍸 I	6
12:00 – 1:00 PM	𝍸 III	8

STOP Compliance Data Sheet

Name: Travis Flowers	Date: 6/22/2017	Direction: SB
Location: 13th St & Longfellow St, NW	Segment: 13th Street, NW	

Interval		Total
10:00 - 11:00 AM		139
11:00 – 12:00 PM		148
12:00 – 1:00 PM		130

Name: Carlos	Date: 6/13/17	Direction: NB
Location: 13th St & Madison St, NW	Segment: 13th Street, NW	

Interval		Total
10:00 - 11:00 AM		142
11:00 – 12:00 PM		125
12:00 – 1:00 PM		152

STOP Compliance Data Sheet

Name: Bolu	Date: 12-22-2017	Direction: EB
Location: Sheridan Street & 7th Street	Segment: Sheridan Street.	

Interval		Total
10:00 - 11:00 AM	卌 卌 卌 卌 卌 I	26
11:00 – 12:00 PM	卌 卌 卌 卌 卌 卌 卌 I	36
12:00 – 1:00 PM	卌 卌 II	12

Name: Babin	Date: 12-22-2017	Direction: WB
Location: Sheridan Street & 9th Street, NW	Segment: Sheridan Street.	

Interval		Total
10:00 - 11:00 AM	卌 卌 卌 卌 III	23
11:00 – 12:00 PM	卌 卌 卌 II	17
12:00 – 1:00 PM	卌 卌 卌 卌 卌 IIII	29

STOP Compliance Data Sheet

Name: Travis Flowers | Date: 6/12/2017 | Direction: EB

Location: Aspen St & 4th St, NW | Segment: Aspen Street, NW

Interval		Total
10:00 - 11:00 AM		85
11:00 – 12:00 PM		67
12:00 – 1:00 PM		59

Name: Babin | Date: 6/12/2017 | Direction: WB

Location: Aspen St. & 6th St, NW. | Segment: Aspen St, NW.

Interval		Total
10:00 - 11:00 AM		42
11:00 – 12:00 PM		48
12:00 – 1:00 PM		23

STOP Compliance Data Sheet

Name: Travis Flowers	Date: 6/12/2017	Direction: SB
Location: 5th St & Whittier St, NW	Segment: 5th Street, NW	

Interval		Total
10:00 - 11:00 AM		40
11:00 – 12:00 PM		30
12:00 – 1:00 PM		50

Name: Carlos	Date: 6/7/2017	Direction: NB
Location: 5th St & Butternut St, NW	Segment: 5th St, NW	

Interval		Total
10:00 - 11:00 AM		33
11:00 – 12:00 PM		24
12:00 – 1:00 PM		24

STOP Compliance Data Sheet

Name: Carlos | Date: 6/6/17 | Direction: NB

Location: North Dakota Ave & Rittenhouse St | Segment: North Dakota

Interval		Total
10:00 - 11:00 AM	||||	4
11:00 – 12:00 PM	卌 卌 ||	12
12:00 – 1:00 PM	卌 |||	8

Name: Travis | Date: 6/12/2017 | Direction: SB

Location: North Dakota Ave & Quackenbos St NW | Segment: North Dakota Avenue

Interval		Total
10:00 - 11:00 AM	卌 卌 卌 卌 ||||	24
11:00 – 12:00 PM	卌 卌 卌 卌 卌 |||	28
12:00 – 1:00 PM	卌 卌 卌 卌 卌 卌 ||||	34

STOP Compliance Data Sheet

Name: BABIN | Date: 9/14/2017 | Direction: NB

Location: Sargent Road & Buchanan St NE | Segment: Sargent Road

Interval		Total
10:00 - 11:00 AM		74
11:00 – 12:00 PM		86
12:00 – 1:00 PM		113

Name: AY | Date: 9/14/2017 | Direction: SB

Location: Sargent Road & Allison Street | Segment: Sargent Road

Interval		Total
10:00 - 11:00 AM		126
11:00 – 12:00 PM		106
12:00 – 1:00 PM		112

STOP Compliance Data Sheet

Name: AY | Date: 9/15/2017 | Direction: NB

Location: 20th St & Lawrence St NE | Segment: 20th Street, NE

Interval		Total
10:00 - 11:00 AM	HHH HHH HHH HHH HHH HHH II	32
11:00 – 12:00 PM	HHH HHH HHH HHH I	21
12:00 – 1:00 PM	HHH HHH HHH HHH HHH	25

Name: BABIN | Date: 9/15/2017 | Direction: SB

Location: 20th St & Jackson St, NE | Segment: 20th Street, NE

Interval		Total
10:00 - 11:00 AM	HHH HHH HHH HHH HHH HHH HHH I	36
11:00 – 12:00 PM	HHH HHH HHH HHH HHH IIII	29
12:00 – 1:00 PM	HHH HHH HHH HHH HHH HHH	30

STOP Compliance Data Sheet

Name: Mel | Date: 11/21/17 | Direction: SB

Location: 3rd Street & L Street, NE | Segment: 3rd Street, NE

Interval		Total
10:00 - 11:00 AM	卌 卌 卌 ||||	19
11:00 – 12:00 PM	卌 卌 卌 ||	17
12:00 – 1:00 PM	卌 卌 卌 ||	17

Name: Shawn | Date: 11/21/17 | Direction: NB

Location: 3rd Street & M Street, NE | Segment: 3rd Street, NE

Interval		Total
10:00 - 11:00 AM	卌 卌 卌 卌 卌 卌 卌	35
11:00 – 12:00 PM	卌 卌 卌 卌 卌 ||||	29
12:00 – 1:00 PM	卌 卌 卌 卌 卌 卌 卌 卌 卌 卌 |||	53

STOP Compliance Data Sheet

Name: Mel	Date: 11/21/2017	Direction: NB
Location: 5th Street & M Street, NE		Segment: 5th Street, NE

Interval		Total
10:00 - 11:00 AM	卌 卌 卌 卌 III	23
11:00 – 12:00 PM	卌 卌 卌 卌 卌 卌 卌 IIII	39
12:00 – 1:00 PM	卌 卌 卌 卌 卌 卌 卌 卌 III	43

Name: Mel	Date: 11/21/2017	Direction: SB
Location: 5th Street & L Street, NE		Segment: 5th Street, NE

Interval		Total
10:00 - 11:00 AM	卌 IIII	9
11:00 – 12:00 PM	卌 卌 II	12
12:00 – 1:00 PM	卌 III	8

STOP Compliance Data Sheet

Name: Babin	Date: 1/10/2018	Direction: NB
Location: 6th St & Orleans Pl, NE		Segment: 6th St, NE

Interval		Total
10:00 - 11:00 AM		135
11:00 – 12:00 PM		167
12:00 – 1:00 PM		207

Name: Shawn	Date: 11/21/2017	Direction: SB
Location: 6th St & L Street, NE		Segment: 6th St, NE

Interval		Total
10:00 - 11:00 AM		88
11:00 – 12:00 PM		85
12:00 – 1:00 PM		108

STOP Compliance Data Sheet

Name: Babin	Date: 11/21/2017	Direction: NB
Location: 7th St & Morton Place NE		Segment: 7th Street

Interval		Total
10:00 - 11:00 AM	~~||||~~ ~~||||~~ |||	13
11:00 – 12:00 PM	~~||||~~ ~~||||~~	10
12:00 – 1:00 PM	~~||||~~ ~~||||~~ |||	13

Name: Babin.	Date: 11/21/2017	Direction: NB
Location: 7th Street & L Street NE		Segment: 7th Street.

Interval		Total
10:00 - 11:00 AM	~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~	20
11:00 – 12:00 PM	~~||||~~ ~~||||~~ ~~||||~~		16
12:00 – 1:00 PM	~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~	30

STOP Compliance Data Sheet

Name: Shawn	Date: 11/14/2017	Direction: SB
Location: 11th & D Street, NE	Segment: 11th Street.	

Interval		Total
10:00 - 11:00 AM	HHT HHT HHT HHT HHT, HHT HHT HHT HHT HHT, HHT HHT HHT III	68
11:00 – 12:00 PM	HHT HHT HHT HHT HHT, HHT HHT HHT HHT HHT, HHT I	56
12:00 – 1:00 PM	HHT HHT HHT HHT HHT, HHT HHT HHT HHT HHT, HHT HHT HHT HHT II	72

Name: Shawn	Date: 11/14/2017	Direction: NB
Location: 11th & E St, NE	Segment: 11th St.	

Interval		Total
10:00 - 11:00 AM	HHT HHT I	11
11:00 – 12:00 PM	HHT HHT	10
12:00 – 1:00 PM	HHT HHT II	12

STOP Compliance Data Sheet

Name: Mel | Date: 11-14-17 | Direction: NB

Location: 13th Street & F Street, NE | Segment: 13th Street, NE

Interval		Total
10:00 - 11:00 AM		91
11:00 – 12:00 PM		65
12:00 – 1:00 PM		65

Name: Mel | Date: 11-14-17 | Direction: SB

Location: 13th Street & D Street, NE | Segment: 13th Street, NE

Interval		Total
10:00 - 11:00 AM		17
11:00 – 12:00 PM		15
12:00 – 1:00 PM		25

STOP Compliance Data Sheet

Name: AY	Date: 11/30/2017	Direction: SB
Location: 14th & D Street, NE		Segment: 14th Street NE

Interval		Total
10:00 - 11:00 AM	(tally marks)	63
11:00 – 12:00 PM	(tally marks)	49
12:00 – 1:00 PM	(tally marks)	63

Name:	Date:	Direction:
Location:		Segment:

Interval		Total
10:00 - 11:00 AM		
11:00 – 12:00 PM		
12:00 – 1:00 PM		

STOP Compliance Data Sheet

Name: BOLU	Date: 12/12/2017	Direction: SB
Location: 9th Street & North Carolina		Segment: 9th Street, SE

Interval		Total
10:00 - 11:00 AM	卌 卌 卌 卌 ||||	24
11:00 – 12:00 PM	卌 卌 卌 ||||	19
12:00 – 1:00 PM	卌 卌 卌 |	16

Name: BOLU	Date: 12/12/2017	Direction: NB
Location: 9th Street & North Carolina.		Segment: 9th Street, SE

Interval		Total
10:00 - 11:00 AM	卌 卌 卌 卌 卌, 卌 卌 卌	40
11:00 – 12:00 PM	卌 卌 卌 卌 ||||	24
12:00 – 1:00 PM	卌 卌 卌	15

STOP Compliance Data Sheet

Name: BOLO	Date: 12/14/2017	Direction: WB
Location: G Street and 9th Street, SE		Segment: G Street, SE

Interval		Total
10:00 - 11:00 AM	𝍸 𝍸 𝍸 𝍸 𝍸	25
11:00 – 12:00 PM	𝍸 𝍸 𝍸 I	16
12:00 – 1:00 PM	𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 II	37

Name: BOLU	Date: 12/14/2017	Direction: EB
Location: G Street and 10th Street, SE		Segment: G Street, SE

Interval		Total
10:00 - 11:00 AM	𝍸 𝍸 𝍸 𝍸 𝍸 I	26
11:00 – 12:00 PM	𝍸 𝍸 𝍸 𝍸	20
12:00 – 1:00 PM	𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 II	32

APPENDIX B:
SIGNAL TIMING DATA COLLECTION SHEET

Descriptive Statistics

STOP-sign Compliance

			Statistic	Std. Error
Compliance Rate	Mean		49.6981	3.32961
	95% Confidence Interval for Mean	Lower Bound	43.0226	
		Upper Bound	56.3736	
	5% Trimmed Mean		48.9994	
	Median		45.8333	
	Variance		609.747	
	Std. Deviation		24.69305	
	Minimum		6.19	
	Maximum		100.00	
	Range		93.81	
	Interquartile Range		35.21	
	Skewness		.480	.322
	Kurtosis		-.590	.634
Distance (ft)	Mean		461.15	22.899
	95% Confidence Interval for Mean	Lower Bound	415.24	
		Upper Bound	507.05	
	5% Trimmed Mean		452.93	
	Median		436.00	
	Variance		28839.645	
	Std. Deviation		169.822	
	Minimum		142	
	Maximum		885	
	Range		743	
	Interquartile Range		237	
	Skewness		.715	.322
	Kurtosis		.177	.634

Control Delay and Average Travel Speed

			Statistic	Std. Error
"Before" Control Delay AM	Mean		29.93	4.331
	95% Confidence Interval for Mean	Lower Bound	21.08	
		Upper Bound	38.79	
	5% Trimmed Mean		26.44	
	Median		23.00	
	Variance		562.616	
	Std. Deviation		23.720	
	Minimum		11	
	Maximum		133	
	Range		122	
	Interquartile Range		18	
	Skewness		3.155	.427
	Kurtosis		12.264	.833
"After" Control Delay AM	Mean		27.23	4.341
	95% Confidence Interval for Mean	Lower Bound	18.36	
		Upper Bound	36.11	
	5% Trimmed Mean		23.56	
	Median		18.00	
	Variance		565.220	
	Std. Deviation		23.774	
	Minimum		11	
	Maximum		130	
	Range		119	
	Interquartile Range		17	
	Skewness		3.166	.427
	Kurtosis		12.033	.833
"Before" Average Speed AM	Mean		6.50	.464
	95% Confidence Interval for Mean	Lower Bound	5.55	
		Upper Bound	7.45	
	5% Trimmed Mean		6.50	
	Median		6.50	
	Variance		6.466	
	Std. Deviation		2.543	
	Minimum		1	
	Maximum		12	
	Range		11	

	Interquartile Range		3	
	Skewness		-.013	.427
	Kurtosis		.044	.833
"After" Average Speed AM	Mean		7.13	.527
	95% Confidence Interval for Mean	Lower Bound	6.06	
		Upper Bound	8.21	
	5% Trimmed Mean		7.17	
	Median		7.00	
	Variance		8.326	
	Std. Deviation		2.886	
	Minimum		1	
	Maximum		13	
	Range		12	
	Interquartile Range		5	
	Skewness		-.318	.427
	Kurtosis		-.252	.833
"Before" Control Delay PM	Mean		28.07	3.295
	95% Confidence Interval for Mean	Lower Bound	21.33	
		Upper Bound	34.81	
	5% Trimmed Mean		25.74	
	Median		23.00	
	Variance		325.651	
	Std. Deviation		18.046	
	Minimum		11	
	Maximum		98	
	Range		87	
	Interquartile Range		12	
	Skewness		2.441	.427
	Kurtosis		7.185	.833
"After" Control Delay PM	Mean		23.80	2.992
	95% Confidence Interval for Mean	Lower Bound	17.68	
		Upper Bound	29.92	
	5% Trimmed Mean		21.44	
	Median		19.50	
	Variance		268.579	
	Std. Deviation		16.388	
	Minimum		10	
	Maximum		91	

	Range		81	
	Interquartile Range		9	
	Skewness		2.913	.427
	Kurtosis		9.658	.833
"Before" Average Speed PM	Mean		6.50	.472
	95% Confidence Interval for Mean	Lower Bound	5.54	
		Upper Bound	7.46	
	5% Trimmed Mean		6.37	
	Median		7.00	
	Variance		6.672	
	Std. Deviation		2.583	
	Minimum		3	
	Maximum		13	
	Range		10	
	Interquartile Range		4	
	Skewness		.675	.427
	Kurtosis		-.126	.833
"After" Average Speed PM	Mean		6.93	.447
	95% Confidence Interval for Mean	Lower Bound	6.02	
		Upper Bound	7.85	
	5% Trimmed Mean		6.85	
	Median		7.00	
	Variance		5.995	
	Std. Deviation		2.449	
	Minimum		3	
	Maximum		13	
	Range		10	
	Interquartile Range		4	
	Skewness		.490	.427
	Kurtosis		-.003	.833

```
* NonLinear Regression.
MODEL PROGRAM  b1=100 b2=-45 b3=0.057.
COMPUTE  PRED_=b1+b2*EXP(b3*Distanceft).
CNLR  CompliaceRate
  /OUTFILE='C:\Users\adamg\AppData\Local\Temp\spss2864\SPSSFNLR.TMP'
  /PRED PRED_
  /BOUNDS b1 >= 0; b2 <= 0; b3 <= -0.001; b1 <= 99.99
  /SAVE PRED RESID DERIVATIVES
  /CRITERIA STEPLIMIT 2 ISTEP 1E+20.
```

Constrained Nonlinear Regression Analysis

Iteration History[b]

Iteration Number[a]	Residual Sum of Squares	Parameter		
		b1	b2	b3
0.2	2617.811	99.990	-45.000	-.001
1.3	2451.357	99.102	-46.324	-.001
2.2	2431.435	99.102	-46.324	-.001
3.1	2071.431	93.046	-48.377	-.002
4.2	1949.635	93.430	-49.890	-.002
5.1	1863.581	92.893	-52.690	-.002
6.1	1819.056	92.344	-55.247	-.002
7.1	1782.795	92.287	-57.983	-.002
8.1	1736.718	93.107	-61.427	-.002
9.2	1656.825	95.923	-66.863	-.002
10.1	1612.576	99.990	-70.799	-.002
11.1	1577.952	99.990	-69.661	-.002
12.1	1565.917	99.990	-67.218	-.002
13.1	1565.610	99.990	-66.924	-.002
14.1	1565.600	99.990	-66.901	-.002
15.1	1565.600	99.990	-66.900	-.002
16.1	1565.600	99.990	-66.900	-.002

Derivatives are calculated numerically.

a. Major iteration number is displayed to the left of the decimal, and minor iteration number is to the right of the decimal.

b. Run stopped after 16 iterations. Optimal solution is found.

Parameter Estimates

Parameter	Estimate	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
b1	99.990	13.776	72.345	127.635
b2	-66.900	8.102	-83.158	-50.642
b3	-.002	.001	-.004	-6.161E-5

Correlations of Parameter Estimates

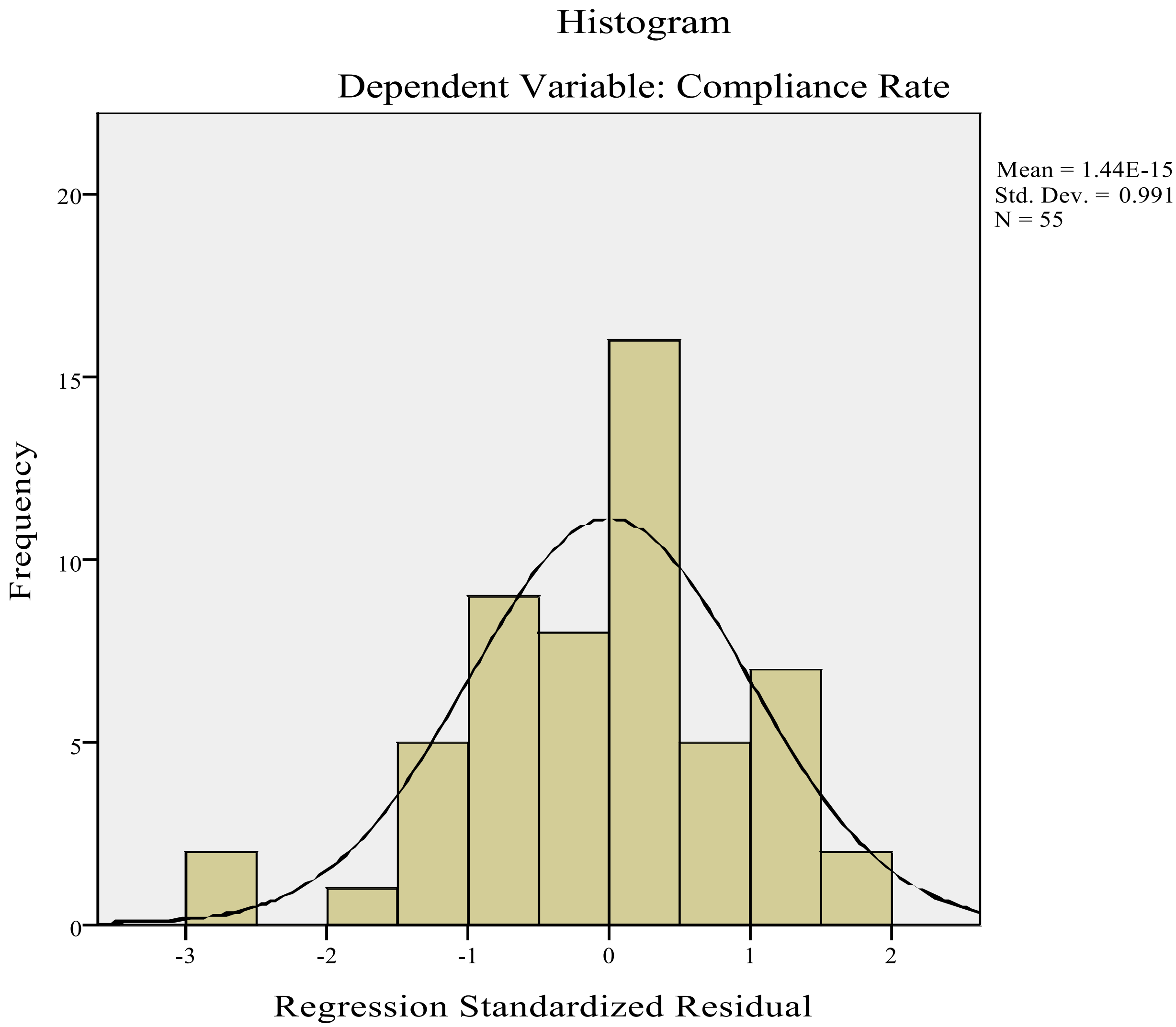
	b1	b2	b3
b1	1.000	-.815	.980
b2	-.815	1.000	-.689
b3	.980	-.689	1.000

ANOVA[a]

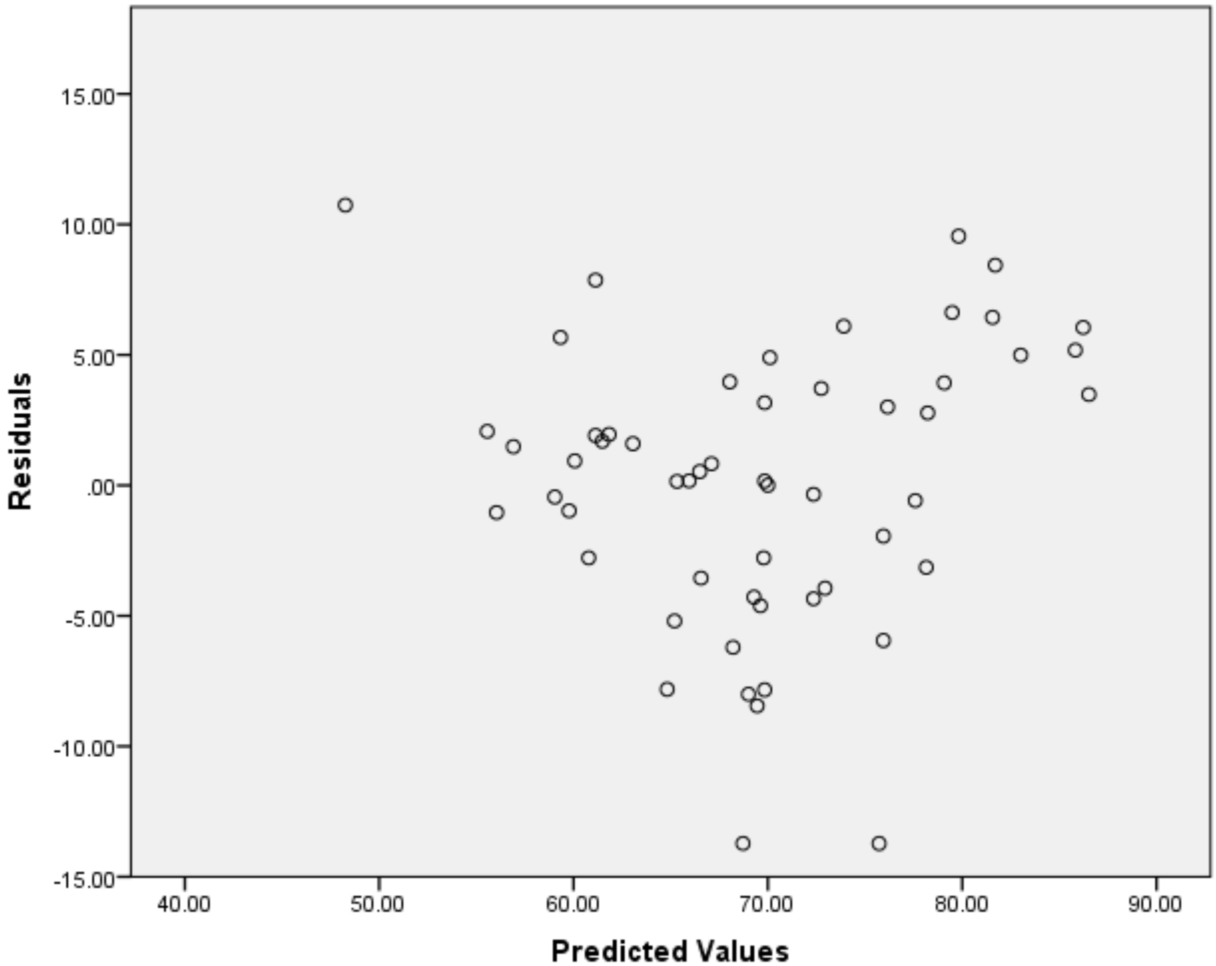
Source	Sum of Squares	df	Mean Squares
Regression	272673.183	3	90891.061
Residual	1565.600	52	30.108
Uncorrected Total	274238.783	55	
Corrected Total	5983.953	54	

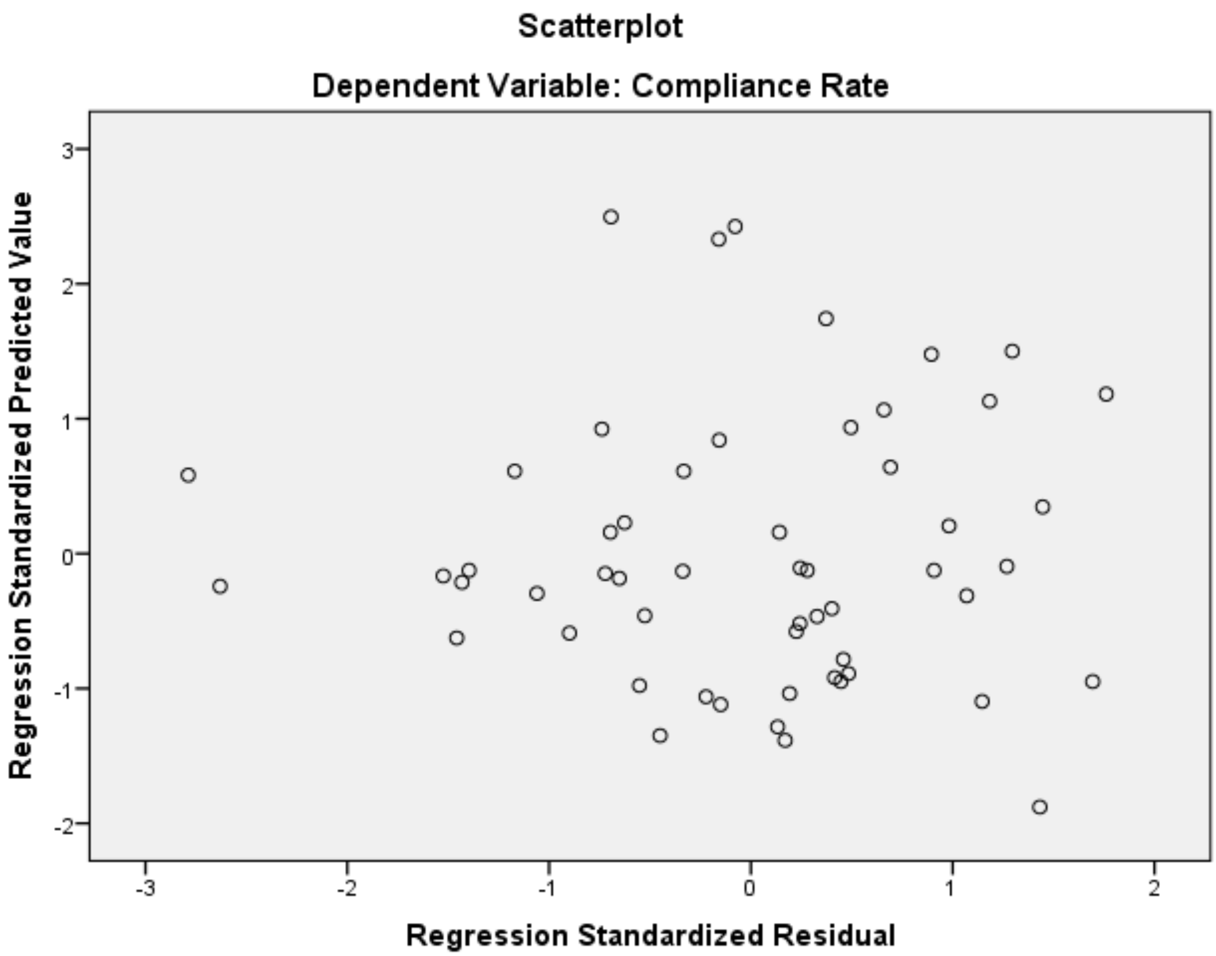
Dependent variable: Compliance Rate

a. R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .738.


Histogram
Dependent Variable: Compliance Rate
Mean = 1.44E-15
Std. Dev. = 0.991
N = 55
Frequency
0
5
10
15
20
-3
-2
-1
0
1
2
Regression Standardized Residual

Test for Heteroscedastic




Scatterplot
Dependent Variable: Compliance Rate
Regression Standardized Predicted Value
3
2
1
0
-1
-2
-3
-2
-1
0
1
2
Regression Standardized Residual

T-Test - Control Delay

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	"Before" Control Delay AM	29.93	30	23.720	4.331
	"After" Control Delay AM	27.23	30	23.774	4.341
Pair 2	"Before" Control Delay PM	28.07	30	18.046	3.295
	"After" Control Delay PM	23.80	30	16.388	2.992

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	"Before" Control Delay AM & "After" Control Delay AM	30	.983	.000
Pair 2	"Before" Control Delay PM & "After" Control Delay PM	30	.930	.000

Paired Samples Test

		Paired Differences			
					95% Confidence ...
		Mean	Std. Deviation	Std. Error Mean	Lower
Pair 1	"Before" Control Delay AM - "After" Control Delay AM	2.700	4.340	.792	1.079
Pair 2	"Before" Control Delay PM - "After" Control Delay PM	4.267	6.648	1.214	1.784

Paired Samples Test

		Paired ...			
		95% Confidence Interval of the ...			
		Upper	t	df	Sig.
Pair 1	"Before" Control Delay AM - "After" Control Delay AM	4.321	3.407	29	.002
Pair 2	"Before" Control Delay PM - "After" Control Delay PM	6.749	3.515	29	.001

T-Test -Average Travel Speed

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	"Before" Average Speed AM	6.50	30	2.543	.464
	"After" Average Speed AM	7.13	30	2.886	.527
Pair 2	"Before" Average Speed PM	6.50	30	2.583	.472
	"After" Average Speed PM	6.93	30	2.449	.447

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	"Before" Average Speed AM & "After" Average Speed AM	30	.912	.000
Pair 2	"Before" Average Speed PM & "After" Average Speed PM	30	.910	.000

Paired Samples Test

		Paired Differences			
					95% Confidence
		Mean	Std. Deviation	Std. Error Mean	Lower
Pair 1	"Before" Average Speed AM - "After" Average Speed AM	-.633	1.189	.217	-1.077
Pair 2	"Before" Average Speed PM - "After" Average Speed PM	-.433	1.073	.196	-.834

Paired Samples Test

		Paired ... 95% Confidence Interval of the ...			
		Upper	t	df	Sig.
Pair 1	"Before" Average Speed AM - "After" Average Speed AM	-.190	-2.919	29	.007
Pair 2	"Before" Average Speed PM - "After" Average Speed PM	-.033	-2.213	29	.035

Mean Absolute Percentage Error Analysis

Intersection Name	Observed Compliance Rate (%)	Predicted Compliance Rates (%)	Absolute Error	Absolute Percentage (%)
11th Street NE & D Street NE	61.00	69.45	8.45	13.85
11th Street NE & E Street NE	55.00	56.04	1.04	1.89
11th Street NW & V Street NW	67.02	66.49	0.53	0.79
11th Street NW & W Street NW	70.00	75.94	5.94	8.49
13th Street NE & Allison Street NE	90.00	86.52	3.48	3.87
13th Street NE & Buchanan Street NE	59.00	48.26	10.74	18.20
13th Street NE & D Street NE	70.00	70.00	0.00	0.00
13th Street NE & F Street NE	61.00	60.06	0.94	1.54
13th Street NW & Fairmont Street NW	60.00	65.20	5.20	8.67
13th Street NW & Girard Street NW	65.48	65.32	0.16	0.24
13th Street NW & Longfellow Street NW	63.00	66.56	3.56	5.65
13th Street NW & Madison Street NW	86.11	79.49	6.62	7.69
14th Street NE & D Street NE	57.00	64.82	7.82	13.72
20th Street NE & Jackson Street NE	63.17	61.48	1.69	2.68
20th Street NE & Lawrence Street NE	58.00	60.78	2.78	4.79
3rd Street NE & L Street NE	62.00	69.83	7.83	12.63
3rd Street NE & M Street NE	88.00	83.01	4.99	5.67
5th Street NE & L Street NE	67.00	69.78	2.78	4.15
5th Street NE & M Street NE	66.12	65.94	0.18	0.27
5th Street NW & Butternut Street NW	73.00	69.83	3.17	4.34
5th Street NW & Whittier Street NW	69.00	72.94	3.94	5.71
6th Street NE & L Street NE	70.00	69.83	0.17	0.24
6th Street NE & Orleans Place NE	58.39	56.91	1.48	2.53
7th Street NE & L Street NE	65.00	69.62	4.62	7.11
7th Street NE & Morton Place NE	69.00	61.13	7.87	11.41
9th Street SE & North Carolina Avenue SE (NB)	80.00	73.90	6.10	7.62
9th Street SE & North Carolina Avenue SE (SB)	63.04	61.13	1.91	3.04
Aspen Street NW & 4th Street NW	68.00	72.34	4.34	6.38
Aspen Street NW & 6th Street NW	77.00	77.58	0.58	0.75
Decatur Street NW & 15th Street NW	65.00	69.28	4.28	6.58
Decatur Street NW & Piney Branch Road NW	58.80	59.77	0.97	1.65
Fairmont Street NW and 11th Street NW	67.92	67.10	0.82	1.21
Fairmont Street NW and 13th Street NW	88.00	81.56	6.44	7.32
G Street SE & 10th Street SE	63.78	61.83	1.95	3.06
G Street SE & 9th Street SE	64.65	63.05	1.60	2.48
Macomb Street NW & 35th Street NW	83.00	79.07	3.93	4.73
Macomb Street NW & 36th Street NW	55.00	68.72	13.72	24.95
North Dakota Avenue NW & Quackenbos Street NW	74.00	75.94	1.94	2.62
North Dakota Avenue NW & Rittenhouse Street NW	75.00	78.14	3.14	4.19
O Street NW & 12th Street NW (EB)	65.00	59.33	5.67	8.72
O Street NW & 12th Street NW (WB)	62.00	68.21	6.21	10.02
S Street NW & 17th Street NW	62.00	75.72	13.72	22.13
S Street NW & New Hampshire Avenue NW	79.17	76.16	3.01	3.80
Sheridan Street NW & 7th Street NW	90.13	81.70	8.43	9.36
Sheridan Street NW & 9th Street NW	75.00	70.11	4.89	6.52
T Street NW & 11th Street NW	57.63	55.56	2.07	3.59
Taylor Street NW & 13th Street NW	91.00	85.82	5.18	5.69
Taylor Street NW & Kansas Avenue NW	61.00	69.00	8.00	13.11
Upshur Street NW & 7th Street, NW	72.00	68.04	3.96	5.50
Upshur Street NW & 8th Street, NW	76.45	72.74	3.71	4.86
Van Ness Street NW & 37th Street NW	92.27	86.22	6.05	6.56
Van Ness Street NW & 38th Street NW	89.37	79.82	9.55	10.68
Warder Street NW & Newton Place NW	58.59	59.04	0.45	0.77
Woodley Road NW & 35th Street NW	81.00	78.22	2.78	3.43
Woodley Road NW & 36th Street NW	72.00	72.34	0.34	0.47
Mean Absolute Percentage Error				6.14

ACRONYMS AND ABBREVIATIONS

AWSC	All-Way STOP Control
CCTV	Closed Circuit Television
CD	Control Delay
CR	Compliance Rate
DDOT	District Department of Transportation
FHWA	Federal Highway Administration
HCM	Highway Capacity Manual
HUTRC	Howard University Transportation Safety and Data Center
ITS	Intelligent Transportation Systems
LOS	Level of Service
MAPE	Mean Absolute Percentage Error
MOE	Measure of Effectiveness
mph	Miles per Hour
MUTCD	Manual on Uniform Traffic Control Devices
TWSC	Two-Way STOP Control
veh	Vehicle

ENDNOTES

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