Analysis of a Three-Street Traffic System

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This paper indicates the changes in traffic flow characteristics in Washington, D. C., measured on a system of three parallel streets, when the operation of the system was changed from 3 two-way streets to a one-way street on each side of the center two-way street. The center street was designed to promote mass bus transportation movements through traffic signal timing and to provide exclusive bus lanes during peak periods.

Recently developed traffic survey and analysis techniques involving galvanic skin response studies and the operation of the U. S. Bureau of Public Roads' traffic impedance analyzer were utilized. These studies along with standard traffic engineering surveys, measured many of the travel characteristics before and after the operational change. The results indicate that movement was improved for traffic traveling through the new system.

•A SHORT article appeared in a Washington, D. C., paper on December 4, 1961, which stated, "17th and 15th Streets to become one-way today." The article went on to specify the limits of the one-way operation and explained that the D. C. Department of Highways and Traffic wanted to measure the traffic impact of the new one-way pattern before experimenting with exclusive bus lanes in a section of 16th Street. For the rest of the week the city sections of the various newspapers were filled with such headlines as "New One-Way Pattern Disrupts Traffic Flow," "New One-Way Traffic Maze Twists 'Em," and "Traffic Patterns Puzzle Drivers."

After the confusion of the first week settled down, drivers learned to accept the new system. The traffic patterns of the three-street system (15th, 16th and 17th Streets) fluctuated daily while motorists experimented with new travel paths to determine the most desirable route to reach their destination. The traffic signal timing was changed to improve flow characteristics and the resulting parameters were measured and analyzed as reported herein.

SYSTEM CHARACTERISTICS

The three streets studied extensively in this paper (Fig. 1) are located in the northwest portion of the District of Columbia. These streets form part of the north-south corridor between Rock Creek Park and Soldiers Home which carries heavy commuter traffic from the Central Business District (CBD) to the residential areas of northwest Washington and the Maryland suburbs. Other major streets in the corridor include Georgia Avenue, Sherman Avenue, and 13th Street. These other streets were not studied, although it is noted that the operational change of the 15th-, 16th- and 17th-Street system affected their flows to a very minor extent.

The study was limited to a 2-mi length of the three-street system from Columbia Road on the north to "H" Street on the south. All three streets were under two-way

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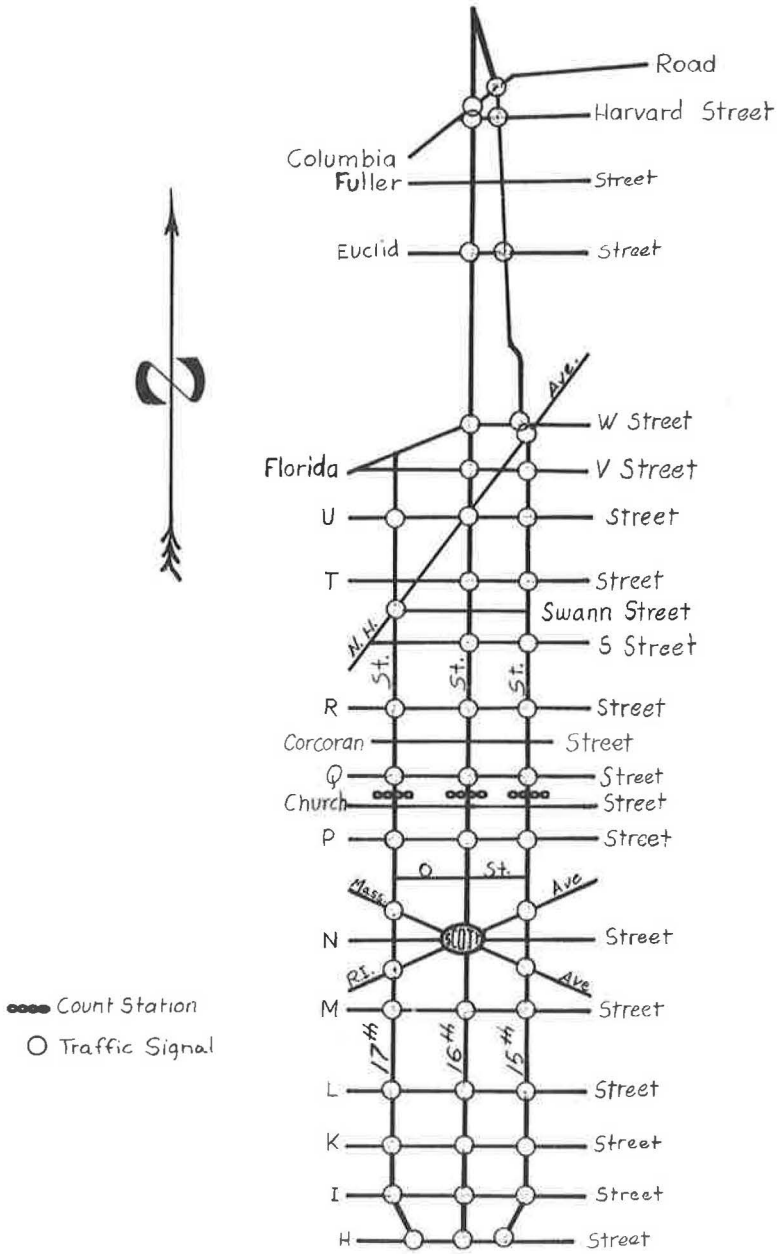

Figure 1. 15th, 16th, and 17th Street System Analysis.

operation before the one-way system was effected. Traffic signal timing favored vehicles traveling toward the CBD during the morning peak period and away from the CBD during the evening rush.

The north end of the system funnels into 16th Street at Irving Street. Sixteenth Street continues to carry traffic toward the District line. The capacity of the system is, therefore, limited by that of 16th Street north of the system, which consists of 5 traffic lanes: unbalanced 3-2 for peak direction flows, and 2-2 with one side parking during off-peak periods.

Sixteenth Street carries D. C. Transit buses throughout the day and serves as a major trunk line for several bus routes extending into the Maryland suburbs. No mass transit was or is using either 15th or 17th Streets for scheduled routes.

The north end of the three-street system is in primarily residential areas with many apartment dwellings located on 15th and 16th Streets; the south end of the system ends in the heart of the business area. Many major office buildings and hotels are located between "M" Street and "H" Street on all three streets.

OPERATIONAL CHANGES

The operational changes effected in December 1961 consisted of making 15th Street one-way northbound and 17th Street one-way southbound, with 16th Street remaining two-way (Fig. 2). Traffic signal timing was coordinated on 15th and 17th Streets to promote through movement all day, while on 16th Street it was designed for a lower speed of progression to produce less transit delay for the buses traveling in the peak direction. It was believed that timing the signals for the lower speeds associated with bus traffic on 16th Street would discourage other traffic from using this street and that the other traffic would be diverted to one of the complementary one-way streets having a through progressive movement.

Because 17th Street does not extend through to the north end of the study area, 16th Street was permanently unbalanced at the north end from Irving Street to Florida Avenue to provide 3 lanes for southbound traffic and two lanes for northbound flow. This extends the unbalanced portion of 16th Street above the system for a. m. peak traffic. The traffic using 17th Street was directed down Florida Avenue from 16th to 17th Street but it was found that one-third of the traffic on 17th Street had used New Hampshire Avenue, located two blocks farther south, to reach the new one-way street.

The parking restrictions were altered to improve traffic movement in the system where necessary, but some parking was restored to the street where it had been prohibited during rush hours. A summary of the parking changes follows.

The "No Standing" restriction was lifted on 15th Street on the portion between "K" Street and Florida Avenue during rush hours because the wide street allowed four lanes of traffic with parking on both sides. Parking was prohibited all day, instead of just during peak periods above Florida Avenue where 15th Street narrows to 3 lanes without parking.

On 16th Street, parking was prohibited above Florida Avenue to allow for the 3-2 unbalancing. Below Florida Avenue, the "No Standing" regulations remained in effect during rush hours where the exclusive bus lanes were installed; however, parking was removed on the opposite curb to allow two moving lanes in each direction during peak periods. Parking continued to be allowed on both sides of 16th Street during off-peak hours.

Parking was removed on the east side of 17th Street during both a. m. and p. m. rush periods. This allowed 3 moving lanes of peak-period traffic and two lanes during the off peak.

Exclusive bus lanes were installed on 16th Street in January for the peak direction of traffic during the morning and evening rush hours. These lanes were designated by signs posted along the curbs of 16th Street. The regulation for the bus lanes excluded all other traffic from using the curb lane except for taxicabs loading or unloading passengers and other vehicles which may enter for the purpose of turning right at any intersection.

After the operational modifications were effected, the Department of Highways and Traffic received complaints in three general areas: (a) the disruption of the circulation pattern, (b) changes in the access of desired parking, and (c) lack of sufficient advanced notification for this major operational change. After the first four months, complaints dropped to a low and intermittent level.

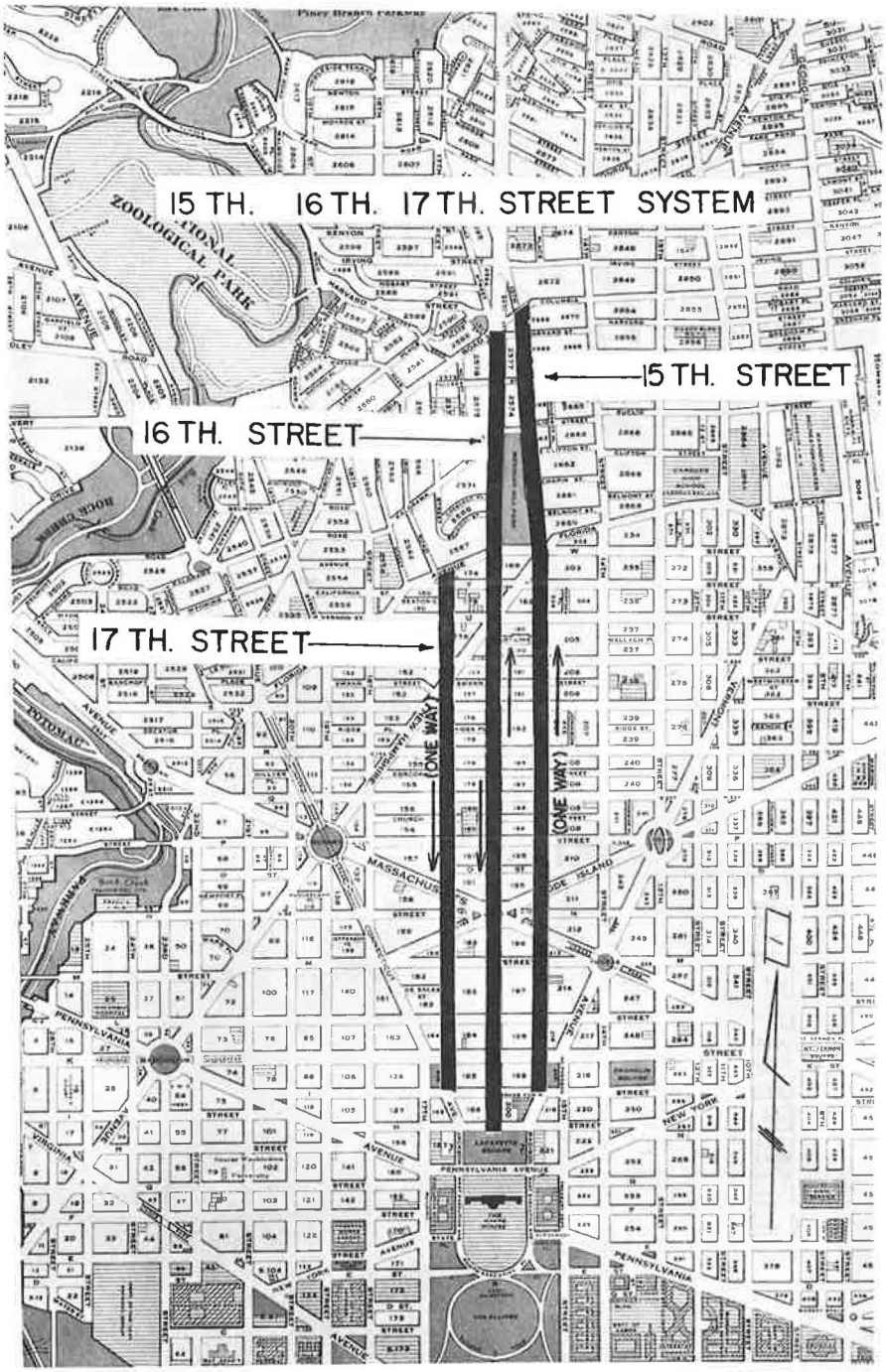
15 TH. 16 TH. 17 TH. STREET SYSTEM
15 TH. STREET
16 TH. STREET
17 TH. STREET
(ONE WAY)
(ONE WAY)
ZOOLOGICAL PARK
ROCK CREEK
POTOMAC
MASSACHUSETTS
RHODE ISLAND
PENNSYLVANIA AVENUE
NEW YORK
VIRGINIA

Figure 2.

STUDY PROCEDURE

Representatives of the Department of Highways and Traffic met with personnel of the Traffic Operations Division, Washington Office of the U. S. Bureau of Public Roads, to plan and coordinate data collection for measuring the change resulting from the proposed new operation. Because of the urgency to install the system before the Christmas shopping rush, only one full week was available in which to collect various data before the system was changed. The U. S. Bureau of Public Roads agreed to provide a technician and a survey vehicle equipped with a traffic impedance analyzer and a galvanic skin response device. All other recording equipment and personnel were provided by the District of Columbia.

The various phases of this study are divided into the following sections: (1) traffic volume studies; (2) travel characteristics studies: (a) on the system, and (b) crossing the system; (3) driver response studies; and (4) bus operation studies.

The "before" phase was conducted from November 27, 1961 to December 1, 1961. Although several check studies were made on the system during the following year, the complete "after" data were collected exactly one year later. This was to insure that the data were collected under conditions most similar to the "before" situation. The final "after" study was conducted in the period of November 27, 1962 to December 3, 1962.

Traffic Volume Studies

The traffic volume comparison was developed from establishing machine count stations on all three streets near Church Street, approximately midway in the system.

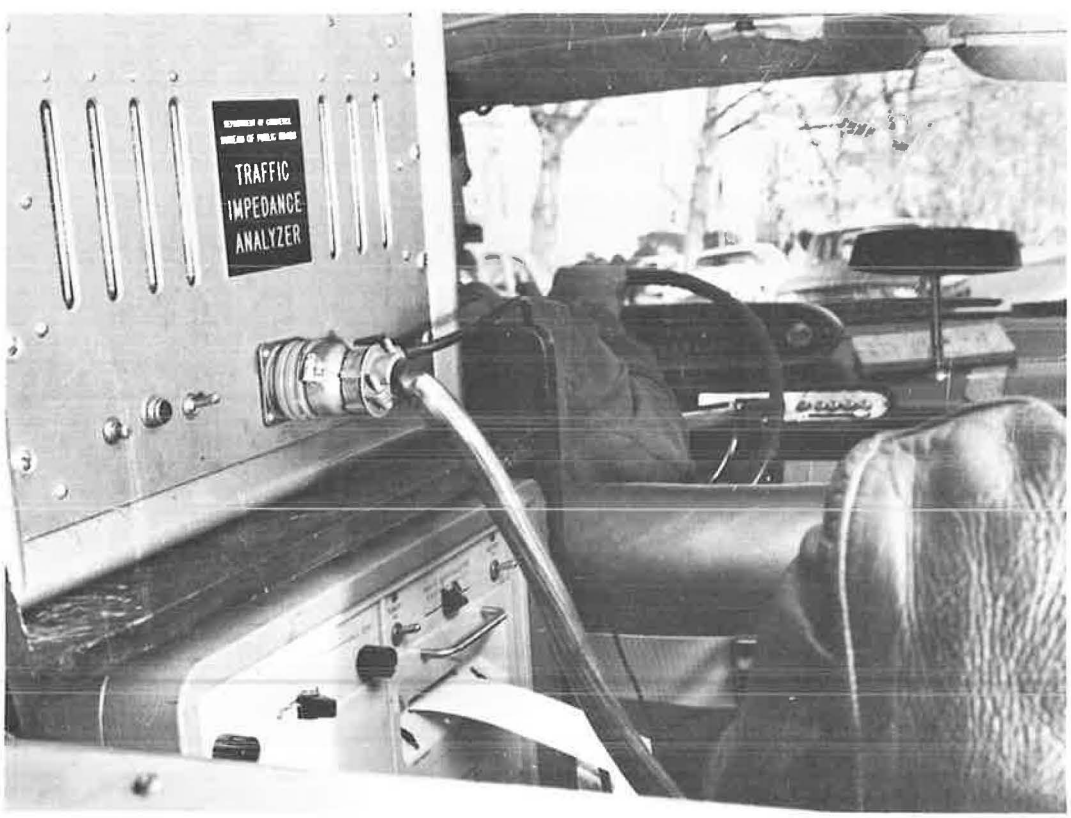

Figure 3. U. S. Bureau of Public Roads' traffic impedance analyzer installed in survey vehicle.

Counts were taken continuously at the beginning of the study period, but they were limited to a one-week count period each month, beginning September 1962. These counts were supplemented with various manual counts conducted at several points on the system for comparison with similar manual counts obtained before the operational change.

Travel Characteristics Studies

Data collection runs were scheduled to cover the three-street system several times each day with the survey vehicle. The survey vehicle was equipped with a traffic impedance analyzer (Fig. 3), which automatically recorded the vehicles' instantaneous speed in miles per hour and the distance traveled on the study section in hundredths of miles each second of the travel run.

To minimize possible study variation, the original drivers were assigned to drive the "after" study using a schedule which closely corresponded to the original driving schedule. Alternate routes were checked where the new one-way streets prohibited the original movement (i. e., southbound on 15th St.). The scheduling insured that the same driver traveled the same section during the same time period the same day of the week. A total of 276 runs were made "before," and 277 runs made during the "after" study for comparative purposes.

Another survey vehicle was assigned to a predetermined route which crossed the system at various points to measure the effects of re-timing the traffic signals installed to promote both the through movement on the new system's one-way streets and the change in 16th Street's signal timing. Standard speed and delay techniques were in-

Figure 4. Galvanic skin response electrode connection to driver's left hand to measure reflexes while traveling through study area.

Figure 5. An observer indicates traffic event which is noted on galvanic skin response time chart. This event is to signify cause for reflex response recorded on chart.

corporated, utilizing a driver and an observer recording the traveled run with a stop watch. The "after" study was scheduled with the same schedule and drivers as before.

Driver Response Studies

The survey vehicle operating on the three-street system was also equipped with galvanic skin response equipment which was connected, as in Figure 4, to measure the driver's response each run. An observer sitting behind the driver held the recording equipment (Fig. 5) and marked on the moving chart the type of event causing the driver's reactions. The various probable causes were predetermined so that it was necessary to mark only a code number for each event. The events recorded are as follows: (1) in stream vehicles, (2) opposing vehicles, (3) turning vehicles, (4) merging and crossing, (5) traffic signals, (6) pedestrians, (7) parking, and (8) other.

Bus Operational Studies

The surveys to determine bus operational characteristics were conducted by having a vehicle follow buses through the study area limits on 16th Street, and the movements and delays experienced by the bus were recorded. Only 20 "before" runs were conducted but many more "after" runs were made during 1962. This phase was eliminated from the November-December 1962 "after study" phase because a more comprehensive

bus study was conducted on 16th Street. During this study, actual observers rode the buses and, by recording length and causes of delays, identified the potential improvements that might accrue from rigidly enforced reserved bus lanes.

ANALYSIS OF DATA

The data collected in this study were analyzed to determine the various effects of the system change invoked upon the motorists. Each street was measured and analyzed separately and the final analysis was compiled to show the results for the three-street system. The analysis is divided in the same phase as stated for data collection.

Traffic Volume Analysis

The traffic recorded at the Church Street counting station showed that the total traffic volume in the system at this point declined slightly after the one-way street system change was effected, but counts conducted in November 1963 showed a slight increase. The

TABLE 1

MONTHLY TRAFFIC VOLUME COMPARISON AT CHURCH STREET, 24-HOUR WEEKDAY AVERAGES

Date	15th Street	16th Street	17th Street	System Total
November 1961[a]	16,879	20,034	9,710	46,623
December 1961[b]	12,708	21,347	8,577	42,632
January 1962	13,790	20,122	10,004	43,916
February	13,281	19,560	10,093	42,934
March	14,153	20,093	10,587	44,833
April	14,588	20,101	9,760	44,449
May	15,085	18,537	10,555	44,177
June	14,700	20,203	11,016	45,919
July	14,118	20,557	10,845	45,520
August	14,568	20,031	10,642	45,241
September	15,139	20,164	11,061	46,364
October	14,192	19,473	11,122	44,787
November	13,832	19,508	11,251	44,591
December	14,793	19,286	12,036	46,115
November 1963	15,511	19,736	11,780	46,947

[a]Before change.
[b]This and all succeeding readings taken after change.

TABLE 2

TOTAL NUMBER VEHICLES FOR SYSTEM ANALYSIS

Street	Direction	AM Peak (7:00-9:30)		AM Off Peak (9:30-12:00)		PM Off Peak (12:00-4:00)		PM Peak (4:00-6:30)		All Day (7:00-6:30)	
		Before	After	Before	After	Before	After	Before	After	Before	After
15th	Northbound	917	1,638	885	1,525	1,805	3,034	2,592	3,868	6,199	10,065
	Southbound	2,267	--	1,399	--	1,724	--	1,155	--	6,545	--
	Total	3,184	1,638	2,284	1,525	3,529	3,034	3,747	3,868	12,744	10,065
16th	Northbound	1,065	939	1,027	979	1,783	1,718	1,829	1,642	5,704	5,278
	Southbound	2,477	2,453	1,647	1,892	2,213	2,402	1,619	1,651	7,966	8,398
	Total	3,542	3,392	2,674	2,871	3,996	4,120	3,448	3,293	13,660	13,676
17th	Northbound	607	--	638	--	1,181	--	1,433	--	3,895	--
	Southbound	1,182	3,246	554	1,678	820	2,149	745	1,777	3,301	8,850
	Total	1,789	3,246	1,192	1,678	2,001	2,149	2,178	1,777	7,160	8,850
Total Traffic	North	2,589	2,577	2,550	2,504	4,769	4,752	5,854	5,510	15,762	15,343
	South	5,926	5,699	3,600	3,570	4,757	4,551	3,519	3,428	17,802	17,248
	On System	8,515	8,276	6,150	6,074	9,526	9,303	9,373	8,938	33,564	32,591

Note: Before = Nov. 1961, after = Nov. 1962.

average 24-hr weekday volume on 17th Street increased from 9,710 to 11,251 in the one-year period, but the volumes on 15th and 16th Streets decreased. The total system volume decreased 4.4 percent in November 1962 but rose 0.7 percent above the "before" volumes in November 1963. A month-by-month summary of the volumes recorded is given in Table 1.

The small volume of traffic lost by the system was most probably diverted to some of the other streets in the corridor. Both 14th and 9th Streets showed a substantial increase during 1962 which more than accounted for the small deficit on the three-street system under study.

It is again pointed out that the capacity of the system is controlled by 16th Street north of the study area because traffic in the system enters this single facility at Irving Street. Therefore, very little traffic volume change was expected from the system's operational modifications.

Table 2 was developed from the count stations established at Church Street to give a direct comparison of each street and each direction of travel on the three-street system for the "before" and "after" study periods in November 1961 and 1962. This comparison indicates the volume changes in the system during each period of the day, with the largest change recorded in the p.m. peak period.

The volumes on the cross streets remained relatively stable in 1962 which indicates that the signal timing changes did not produce a noticable effect on this traffic. This analysis is supported by the travel studies conducted on these streets.

Analysis of Travel Characteristics

Two intermediate check studies were conducted with the Bureau of Public Roads' traffic impedance analyzer between the "before" study and the final "after" study. The results of these runs are summarized in Figures 6 through 13 in the Appendix. These figures illustrate the average measured travel time and the number of stops for each street for each study period.

Both 15th and 17th Streets showed an average improvement during all periods of the study for both travel time and the number of stops experienced by the survey vehicle. The graphs indicated that 16th Street travel characteristics changed very little after the new street system was effected.

To determine the significance of the travel effects, a statistical test was performed on the "before" and "after" run data to determine if an improvement was actually produced for each street. Inasmuch as the same driver was assigned to travel each route

TABLE 3

PAIRED COMPARISON FOR TRAVEL

Street	Direction	Sig. Diff. for Travel Time[a]				Sig. Diff. for No. of Stops[a]			
		AM		PM		AM		PM	
		Peak	Off Peak	Off Peak	Peak	Peak	Off Peak	Off Peak	Peak
15th	Northbound	99	99	95	-	99	95	99	-
	Southbound[b]	99	99	99	99	-	-	-	99
16th	Northbound	95	-	-	-	95	95	-	-
	Southbound	-	-	99	-	-	95	95	-
17th	Northbound[b]	99	99	99	-	99	99	99	99
	Southbound	95	99	99	99	99	99	99	99

[a]At percent confidence level.
[b]"Before" flow prohibited by system change is compared to flow of one-way street for direction indicated.

during the same time period on the same day of the week, it was felt that the differences could best be measured by paired comparisons. Each "after" run was associated with its corresponding "before" run. An arbitrary time limit leeway of 10 minutes was allowed for the beginning times because it was impractical to start each "after" run at the identical beginning time. The corresponding run differences were tabulated and the mean difference and standard deviation were computed for each of the four time periods for each direction on each street. For this comparison, the "after" runs southbound on 17th Street were compared with the "before" runs for southbound on 15th Street, and the "after" northbound on 15th Street was used for comparison with the "before" travel northbound on 17th Street. The significance of the mean difference was computed by using the student's "t" test at the 99 percent confidence level. If a difference was not indicated at this level, the 95 percent confidence level was tried. Both the travel times and the number of stops were tested for each direction on each street for the four test periods. The results are given in Table 3.

As is noted in Table 3, both 15th and 17th Streets provided a significant improvement for the test vehicle during all periods of the day except for northbound on 15th Street during the evening peak period. The traffic signals on this street were already timed for a progressive northbound movement before the street was made one-way.

In addition to the normal analysis involving travel times and the number of stops of each street, the quality of flow for each street was computed as presented by Greenshields (2);

$$Q = \frac{1000\,S}{\Delta s \sqrt{f}} \tag{1}$$

in which

S = average speed,
Δs = accumulative total of speed change per mile, and
f = total number of speed changes per mile.

It was possible to determine values of Δs and f by analyzing the speed data recorded on the tapes produced by the traffic impedance analyzer. The quality of flow values was computed for each run as well as the total for each street for the entire study period. The standard deviation, the standard error and the statistical limits of Q for each street were computed by the method described by Greenshields. The results of this analysis are given in Table 4.

The higher quality numbers indicate better flows were measured. It can be noted that both 15th and 17th Streets improved significantly by the one-way street change. However, the quality of flow for southbound 17th Street during the "after" study was

TABLE 4

QUALITY OF FLOW FOR SYSTEM ANALYSIS

Street	Direction	Study	Quality Q	Std. Dev. S	Std. Error	95% Limits of Q Lower	95% Limits of Q Upper
15th	Northbound	Before	29.51	58.1	8.95	11.6	47.4[a]
		After[a]	79.3	75.1	7.83	63.6[a]	95.0
	Southbound	Before	26.85	28.0	4.30	18.25	35.45
16th	Northbound	Before	28.47	25.6	3.94	20.6	36.35
		After	22.54	11.1	1.67	19.20	25.88
	Southbound	Before	24.09	10.3	1.55	21.0	27.2
		After	20.33	9.56	1.46	17.4	25.3
17th	Northbound	Before	12.26	7.97	1.17	9.9	14.6
	Southbound	Before	10.00	8.86	1.29	7.4	12.6[a]
		After[a]	26.24	23.8	2.47	21.3[a]	31.2

[a]Significant difference in quality of flow.

TABLE 5

AVERAGE TRAVEL TIME IN SECONDS FOR CROSS SYSTEM

Section[a]	AM Peak		AM Off Peak		PM Off Peak		PM Peak		Daily Avg.	
	Before	After	Before	After	Before	After	Before	After	Before	After
1	171.50	196.80	162.86	190.33	185.33	198.53	223.70	208.05	185.85	198.43
2	131.30	113.35	132.71	102.33	115.87	109.13	236.00	147.80	153.97	118.15
3	84.30	57.85	87.00	55.93	103.73	51.13	74.75	72.90	87.45	59.45
4	144.40	153.10	160.43	130.40	137.53	137.47	173.55	162.10	153.98	145.77
5	72.70	47.40	93.14	46.87	102.47	47.07	74.65	71.45	85.74	53.20
6	233.45	220.65	169.07	254.47	181.93	240.53	230.10	245.45	203.64	240.28
7	279.85	274.65	264.50	236.87	252.00	248.47	274.35	268.90	267.68	257.22
8	348.20	178.55	377.43	222.33	391.47	209.67	480.50	200.35	399.40	202.73
Total	1,465.70	1,242.35	1,447.14	1,239.53	1,470.33	1,242.00	1,767.60	1,377.00	1,537.69	1,275.22

Note: Before = Nov. 1961, after = Nov. 1962. [a]Section designations are as follows: 1--westbound, I St.; 2--eastbound, K St.; 3--eastbound, L St.; 4--westbound, K st.; 5--westbound, L St.; 6--eastbound, Q St.; 7--westbound, P St.; 8--eastbound, M St.

not significantly improved over either the "before" or "after" southbound flows on 15th or 16th Streets. It was observed in the field that although the flow on 17th Street ran smoothly through most of the northern and central portion of 17th Street during the "after" study congestion and signal delay were experienced from M Street south.

Results of all speed and delay studies conducted on each street crossing the three-street system were tabulated. The streets traveled were I, K, L, M, P and Q Streets with two directions of travel measured on both K and L Streets. Therefore, 8 sections of cross system movement were studied. Of these 8 sections, only 2 sections showed an increase in travel time experienced by the survey vehicle as an average for the total study day from 7:00 a.m. to 6:30 p.m. The average overall improvement for all the cross streets in travel time was 16 percent. These cross street time savings were fairly consistent for all periods of the day as the travel time measured showed a computed average percentage improvement of 22.0, 15.2, 8.2 and 15.5 for a.m. peak period, a.m. off peak, p.m. off peak and p.m. peak, respectively (see Table 5 for a summary of the results). Because of the variance in the test runs, statistical tests failed to indicate that a significant difference was measured.

This study showed that the signal timing changes did not adversely affect the traffic movements on the cross streets. It may have improved the cross movement slightly for the streets that were surveyed.

Analysis of Driver Reactions

The driver tension responses measured by the galvanic skin response equipment were treated in much the same way that the travel and stop data were analyzed. It was decided on the basis of Michaels' paper (3) to eliminate as much variance as possible between drivers on the routes by scheduling the same drivers to run each route the corresponding period of time during the "after" study. Therefore, it was believed the most accurate analysis could be best performed by paired comparisons.

The mean difference and the standard deviation of the differences of magnitude and number of events for each street during each of the four study periods were computed. The results were used with a student's "t" significance test on the mean differences measured. The results are given in Table 6. The arithmetic mean values for the magnitude and number of events are given in Table 7.

The study shows that the one-way streets, 15th and 17th Streets, produce significantly less driver tensions. The driver tensions remained relatively unchanged in both magnitude and number of events on 16th Street which remained in two-way operation.

More detailed analyses could be performed on the galvanic skin response data collected such as are reported by Cleveland (1) and Michaels (3), but it is considered that the number of events and the total magnitude measured are the most important parameters obtained by the galvanic skin response equipment.

Analysis of Bus Operations

The data collected before the system change and after the installations of signs to effect exclusive bus lanes during rush periods in the direction of heavy passenger flow

TABLE 6

PAIRED COMPARISON FOR GSR

Street	Direction	Sig. Diff. for Magnitude[a]				Sig. Diff. for No. of Events			
		AM		PM		AM		PM	
		Peak	Off Peak	Off Peak	Peak	Peak	Off Peak	Off Peak	Peak
15th	Northbound	99	99	95	-	99	99	99	-
	Southbound[b]	-	-	-	99	-	-	-	99
16th	Northbound	-	99	-	-	-	99	-	-
	Southbound	99	-	-	-	99	-	-	-
17th	Northbound[b]	95	99	95	-	99	99	99	95
	Southbound	99	99	99	-	99	99	99	99

[a] At percent confidence level.
[b] "Before" flow prohibited by system change is compared to flow of one-way street for direction indicated.

TABLE 7

Street	Direction	Avg. GSR Magnitude per Run								Avg. No. of Events Recorded per Run							
		AM				PM				AM				PM			
		Peak		Off Peak		Off Peak		Peak		Peak		Off Peak		Off Peak		Peak	
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
15th	Northbound	44.4	12.5	32.0	11.4	29.0	19.3	34.7	16.9	19.7	7.9	19.0	7.9	19.6	9.7	19.0	9.5
	Southbound	33.3	-	33.7	-	31.8	-	21.1	-	18.4	-	19.1	-	19.7	-	33.5	-
16th	Northbound	28.6	22.9	36.8	16.9	37.4	24.2	32.5	24.1	17.3	17.3	20.6	13.1	21.0	16.6	19.5	15.5
	Southbound	40.6	18.4	28.2	26.7	33.1	23.5	34.6	26.9	21.6	13.9	18.5	17.1	21.0	15.5	20.7	16.1
17th	Northbound	35.5	-	30.9	-	40.3	-	34.5	-	19.5	-	22.8	-	25.2	-	22.2	-
	Southbound	38.7	16.9	42.9	17.5	48.9	19.6	37.3	21.2	20.9	11.2	25.4	13.2	28.3	12.8	24.6	12.5

TABLE 8

BUS LANE STUDY ON 16TH ST., L ST. TO FLORIDA AVE., AVERAGE TRAVEL CHARACTERISTICS

Direction	No. Samples	Passenger Loading (min)	Traffic Delay (min)	Running Time (min)	Total Time (min)	Travel Speed[a] (mph)
Southbound (AM rush hour)						
Before	6	91	64	249	404	9.4
After	5	73	44	274	391	9.7
Northbound (PM rush hour)						
Before	3	69	68	256	393	9.7
After	3	108	26	267	400	9.5

Note: Before = Nov. 1961, after = May 1962.

[a] Average travel speed through system including running and stopped time.

are summarized in Table 8. The number of samples is too limited for a significant conclusion, but the data indicate that very little improvement was obtained by the bus lanes. The delay caused by traffic and traffic signals decreased 53 percent, but the passenger loading and running time increased to offset the improvement.

From observation in the field, it was determined that there was very little observance of the bus lane regulation by motorists. This is most probably due to the lack of rigid enforcement and the fact that bus traffic was not heavy enough to make the demand for this regulation readily apparent.

Two more "after" studies were conducted by observers stationed at each end of the study area recording time and bus numbers. These studies showed a greater improvement than the above study, but the improvement occurred equally throughout the day and was not any greater for the periods the bus lane regulations were in effect than when they were not.

A more comprehensive study of 16th Street as well as other streets was conducted in November 1962. This study was to determine how much improvement could be expected from bus lane operations if they were properly enforced for peak traffic conditions. The results of this study indicated that the travel time of bus operations would improve only a few seconds per mile if exclusive bus lanes were installed on streets where parking is already prohibited in the curb lane. Less than 5 percent of the total bus delay could have been eliminated with enforced exclusive bus lanes. The greatest causes for bus delay were found to be passenger loading and unloading and traffic signal delay, in that order.

Economic Analysis of the System

An analysis of the system was developed to determine the net effect of the street operation change. In this analysis the traffic volume data of the "before" and "after" periods were adjusted to indicate the traffic volume on each street for those motorists who continued to use the system. No monetary analysis could be computed for the small amount of traffic which left the three streets studied.

The mean travel time for each period of each direction of each street was multiplied by the volume of traffic traveling during that period on the respective street to compute total travel time in vehicle seconds. The total time in vehicle seconds of the system "after" the operation change for the study period from 7:00 a.m. to 6:30 p.m. was subtracted from the "before" data. This difference of travel time equaled 404.07 vehicle hours per day which if converted to monetary terms of $1.35 per vehicle hour represents a savings of $545.50 to the motorist in time. The cost savings for the number of stops eliminated by the system indicates an additional daily operating savings of $127.50 using a cost figure of $0.0019 per stop.

Expanding these figures to annual values it appears the three-street system change has produced approximately $131,000 in time savings and $30,600 in operating costs for the weekday users of the system totaling $161,000 per year.

The computations for this analysis are presented in more detail in the Appendix.

CONCLUSIONS

This study showed that although there was only a very slight change in traffic volumes measured on 15th, 16th and 17th Streets the operational improvement, effected by making 15th and 17th Streets one-way, more than justified the new system. This improvement included 11.5 percent less travel time, less driver tension, and 33 percent fewer stops for the traffic using these streets.

The greatest travel improvements were measured for traffic moving counter to the direction of progressive signal timing during peak periods. This is attributed to the traffic signals set for through progressive movements on the one-way streets throughout the entire day.

The traffic parameters for travel on 16th Street remained relatively unchanged. The bus lanes installed on 16th Street were not well observed by other motorists, but an improvement in bus travel time would have been negligible even if the regulations were rigidly enforced.

The operational change did not make a significant difference for traffic crossing the system in either volumes measured or travel time.

It is concluded that by changing 15th and 17th Streets to operate as one-way streets, and timing the signals on 16th Street to favor transit flows, an effective system was devised to improve the flow of vehicular traffic through this portion of Washington, D.C.

REFERENCES

1. Cleveland, Donald E. Driver Tension and Rural Intersection Illumination. Proc. Institute of Traffic Engineers, pp. 10-22, 1961.
2. Greenshields, Bruce D. Quality of Traffic Flow. Bureau of Highway Traffic, Yale Univ. pp. 3-40, 1961.
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Appendix

VOLUME ANALYSIS FOR TRAVEL STUDY

Assumptions:

1. Traffic lost from the system was diverted from the movement that was eliminated; i.e., the loss of northbound traffic was diverted from 17th Street and the loss of southbound traffic was diverted from 15th Street.
2. This comparison is made only for the users that remained on the system. No consideration could be computed for the diverted traffic.

Before—November 1961	AM Peak 7:00 to 9:30	PM Off Peak 12:00 to 4:00
After—November 1962	AM Off Peak 9:30 to 12:00	PM Peak 4:00 to 6:30

REVISED VOLUME CHART FOR TRAVEL COMPARISON

Street	AM Peak	AM Off Peak	PM Off Peak	PM Peak
		Before Northbound		
15th St.	917	885	1,805	2,592
16th St.	1,065	1,027	1,783	1,829
17th St.	595	592	1,164	1,089
Total	2,577	2,504	4,752	5,510
		After Northbound		
15th St.	1,638	1,525	3,034	3,868
16th St.	939	979	1,718	1,642
Total	2,577	2,504	4,752	5,510
System loss	12	46	17	344
		Before Southbound		
15th St.	2,040	1,369	1,518	1,064
16th St.	2,477	1,647	2,213	1,619
17th St.	1,182	554	820	745
Total	5,699	3,570	4,551	3,428
		After Southbound		
16th St.	2,453	1,892	2,402	1,651
17th St.	3,246	1,678	2,149	1,777
Total	5,699	3,570	4,551	3,428
System loss	227	30	206	91

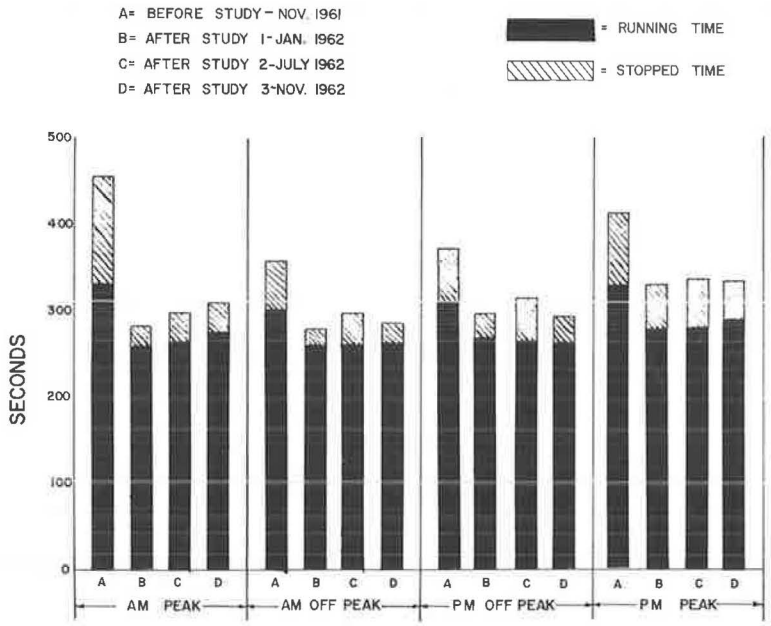

Figure 6. 15th Street, N. W. (northbound).

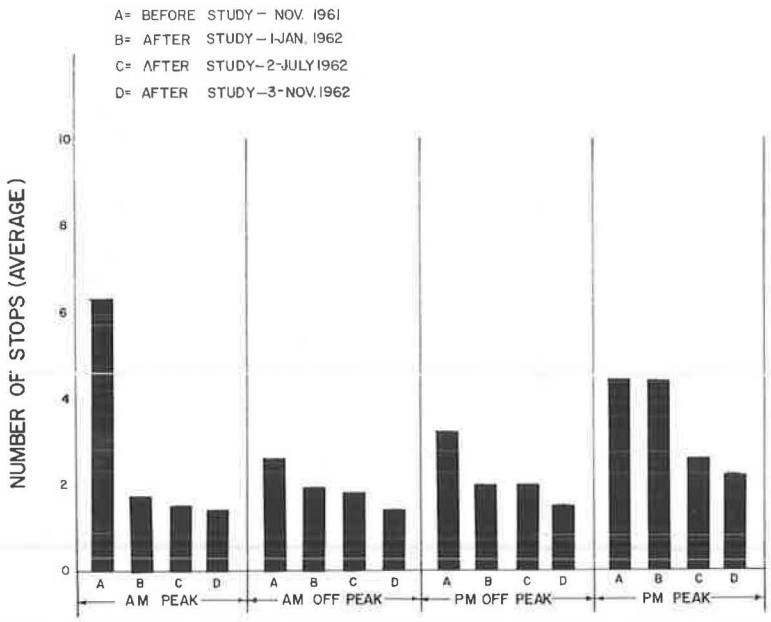

Figure 7. 15th Street, N. W. (northbound).

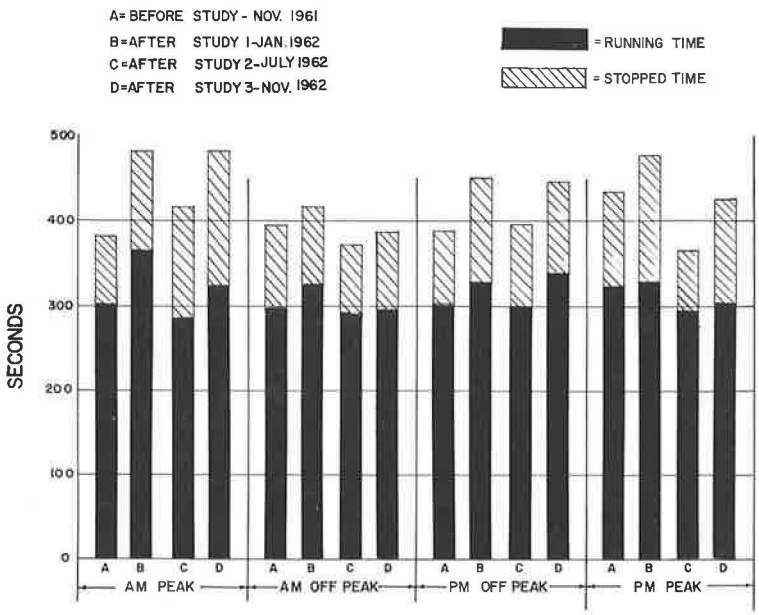

Figure 8. 16th Street, N. W. (northbound).

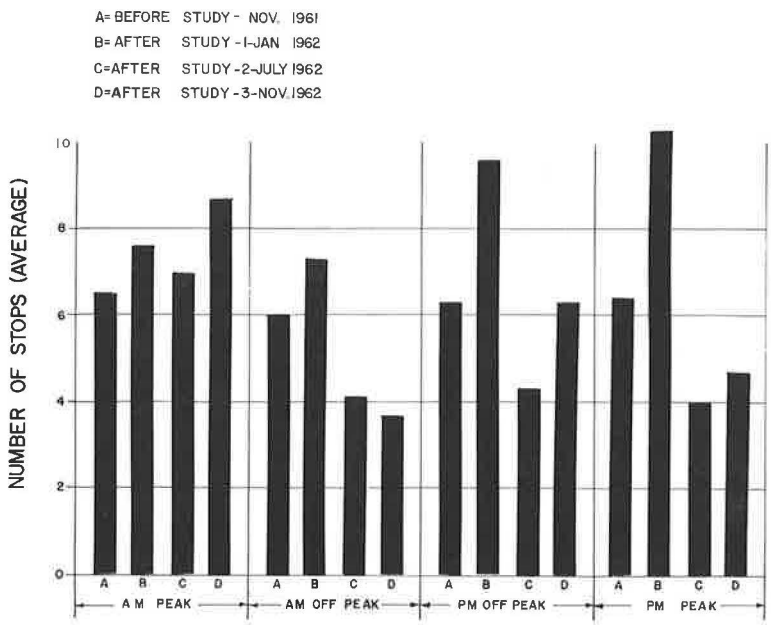

Figure 9. 16th Street, N. W. (northbound).

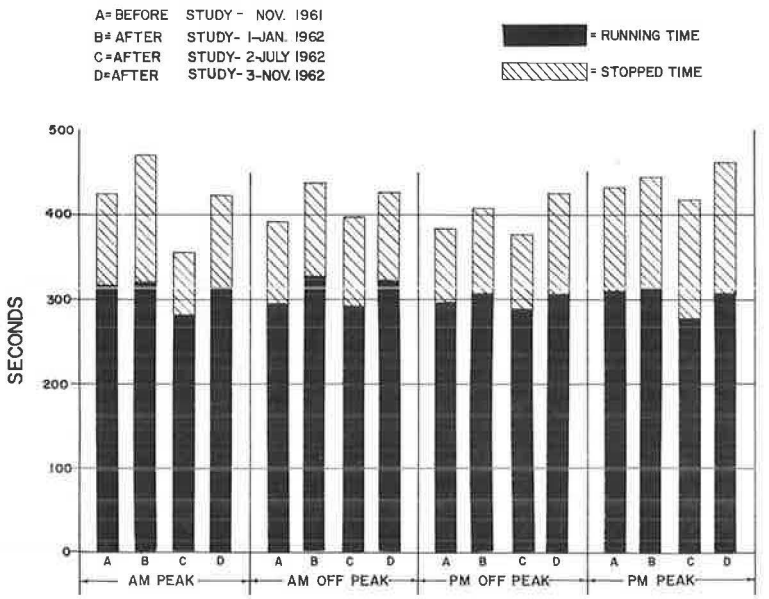

Figure 10. 16th Street, N. W. (southbound).

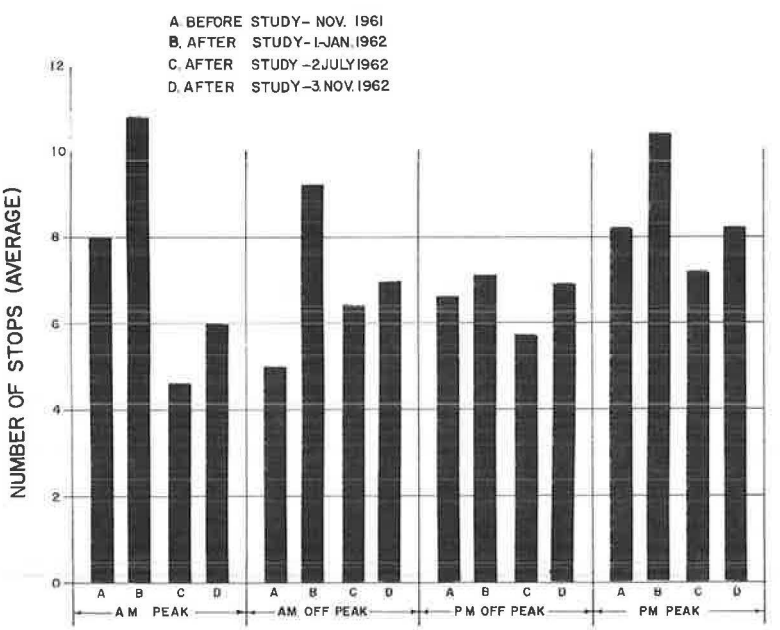

Figure 11. 16th Street, N. W. (southbound).

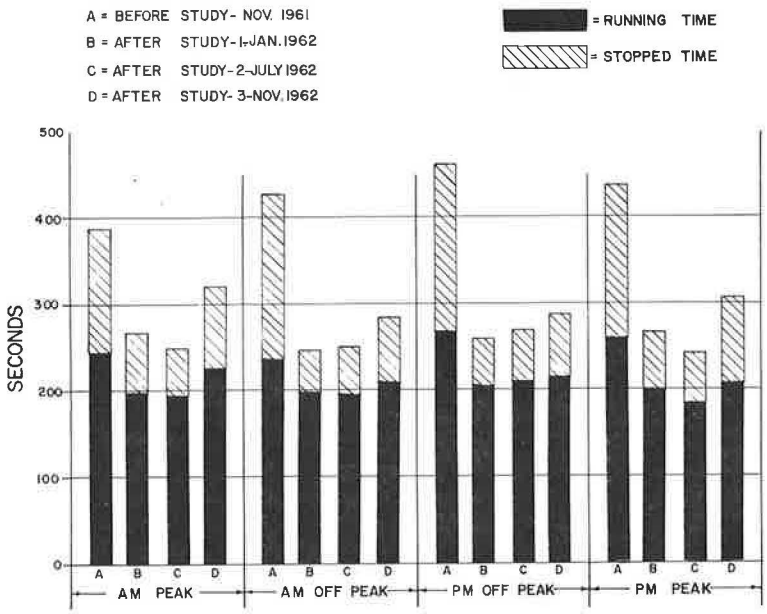

Figure 12. 17th Street, N. W. (southbound).

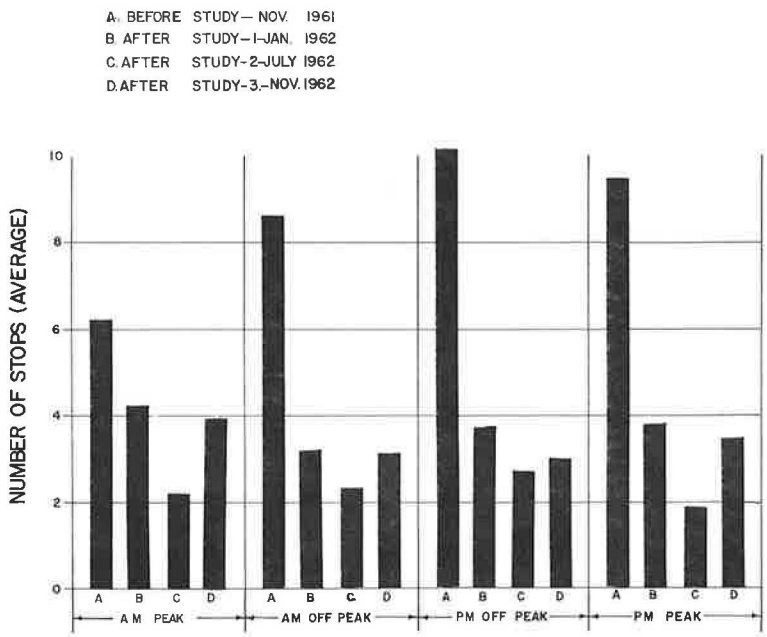

Figure 13. 17th Street, N. W. (southbound).