

Influence of On-Ramp Spacing on Traffic Flow on Atlanta Freeway And Arterial Street System

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The purpose of this study was to determine the influence of ramp spacing on the traffic flow characteristics on the Atlanta Freeway System and city streets influenced by the freeway. Time-lapse photography was used to collect data at four study locations on the freeway. Speed and delay studies were also made on the freeway and surface streets during ramp closure periods and during normal operation of the freeway. Comparisons were made of volumes, speeds, densities, overall travel, and overall travel time on the streets within the system using analysis of variance techniques.

It was found that closing any one of the northbound on-ramps on the North Freeway during the afternoon peak hour improved the overall operating characteristics of the freeway. This improvement was shown by a smoother and more uniform flow of traffic as reflected by the speeds and densities on the freeway with none of the ramps closed.

Closing any one of the northbound on-ramps caused a significant increase in the total travel time in vehicle-minutes within the system. The overall travel in vehicle-miles was not changed significantly by closing any one of the northbound on-ramps within the system.

As a result of this study, it was recommended that the Fourteenth Street northbound on-ramp be closed during the afternoon peak period for three months and that further tests be carried out on a system basis to determine if the Fourteenth Street northbound on-ramp should be closed during the peak period on a permanent basis.

• **THE PURPOSE** of this research was to determine the influence of on-ramp spacing on the traffic flow characteristics of the Atlanta Freeway System and city streets influenced by the freeway. The work was sponsored by the Georgia State Highway Department in cooperation with the U. S. Bureau of Public Roads under a contract with the Georgia Institute of Technology. A systems engineering concept was used wherein the operation of the city streets in the vicinity of the freeway was considered as well as the operation of the freeway. Further studies are being conducted to determine similar information of the influence of off-ramp spacing on the same streets.

There are several factors that influence the location and spacing of interchanges in a freeway system:

1. Marking and directional signing.
2. Maneuver areas and weaving sections.
3. Traffic accidents.
4. Ramp design.

5. Economics.
6. Size of city.
7. Type of area.
8. Existing street pattern.
9. Land use patterns.
10. Balance between freeway and city street travel.
11. Optimization of travel time.

DATA COLLECTION

The study area (Fig. 1) comprises the area lying north of the central business district of Atlanta. It was chosen as the study area because any alterations or changes in

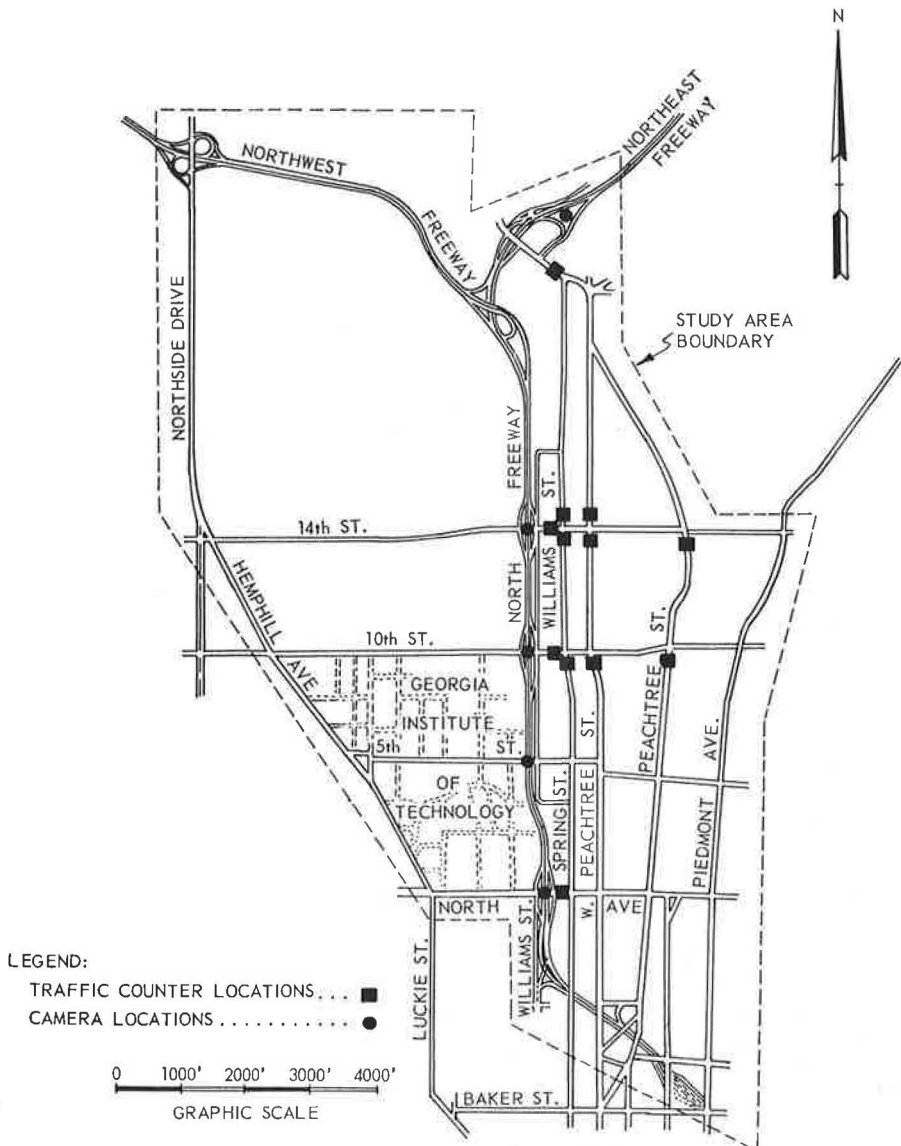


Figure 1. Study area.

TABLE 1

DISTANCES BETWEEN INTERCHANGES FOR VARIOUS RAMP CLOSINGS
IN MILES ON NORTH AND NORTHEAST FREEWAYS

Location	No Ramps Closed, Normal Operation	Northbound On-Ramp Closed		
		North Avenue	10th Street	14th Street
Williams Street ¹				
North Avenue	0.089	0.797	0.089	0.089
10th Street	0.708		1.067	0.708
14th Street	0.359	0.359		1.250
Peachtree Street	0.891	0.891	0.891	
Piedmont Road	1.458	1.458	1.458	1.458

¹Left-hand on-ramp.

ramp spacing would influence traffic flow conditions in this area. Changes in traffic flow outside this area would be small and the methods used to detect changes in conditions would not be sensitive enough to measure this change.

The land use in the study area consists mainly of small businesses, apartment houses, boarding houses, insurance offices, medium and small hotels, service stations, and old residences. The majority of the traffic in the study area during the evening peak hour is traffic which is originating in or is passing through the area rather than having a destination in the study area.

The street system within the study area consists of three arterials running in an east-west direction and five arterials running generally in a north-south direction. The freeway runs north and south approximately in the center of the study area.

Within the study area, the freeway consists of three 12-ft lanes in each direction between the south limits of the study area and the junction of the Northeast and Northwest Freeways. From this junction north, both the Northwest and Northeast Freeways consist of two 12-ft lanes in each direction. The freeways and ramps are constructed of concrete. To provide color contrast, the concrete on the ramps has been darkened.

The interchanges on the North Freeway at North Avenue, 10th Street, and 14th Street are diamond-type interchanges with the on-ramps entering directly onto the freeway with no acceleration lanes provided. The design speed used on the freeway was 50 mph and the design speed used on the ramps was 35 mph. The design hour volume used on the freeway was 1,500 vehicles per lane per hour. The maximum vertical grade used in the design was 5 percent and the maximum horizontal curvature used was 3°. The location at 5th Street is a grade separation only. The freeway from North Avenue to Peachtree Street was completed and opened to traffic in the spring of 1950.

The method used for varying the spacing between ramps without making permanent or semipermanent changes in the freeway was to close certain ramps during the peak period of flow. When a ramp was closed, the interchange was effectively eliminated and the ramp spacing of the "remaining interchanges" was changed. Table 1 gives the distances between interchanges. Each of the northbound on-ramps located at North Avenue, 10th Street, and 14th Street was closed during the afternoon peak period between 4:00 and 6:30 PM, covering a period of 2 weeks. The ramps were closed on the following dates:

14th Street: April 17-21, 24-28, 1961 (Monday through Friday during each week).

10th Street: May 8-12, 15-19, 1961 (Monday through Friday during each week).

North Avenue: October 9-13, 16-20, 1961 (Monday through Friday during each week).

Because a comparison of the effect of ramp closures on the freeway and arterial street operation was being studied, no traffic engineering changes were made on arterial streets influenced by the ramp closure. Each on-ramp was closed separately and two ramps were not closed at the same time. Table 1 gives the distance between interchanges for each ramp closure.

The first week that each ramp was closed, the traffic in the study area was allowed to stabilize to permit motorists to establish new travel patterns. It was assumed that the motorists would distribute themselves throughout the study area so as to optimize their travel desires before the beginning of the second week during which most of the studies were made.

Studies were made at four different positions on the freeway under normal operation, and with the northbound on-ramp closed at North Avenue, 10th Street, and 14th Street. The data collected at these respective positions were the volume, speed, and density in each lane on the freeway and the ramp volume. These data were collected between 4:30 and 5:10 PM and between 5:20 and 6:00 PM by the use of time-lapse movie photography.

The cameras used in making the movies contained sufficient film for 40 min of continuous filming when the film was exposed at a rate of 100 frames per minute. Unloading and reloading the cameras necessitated a 10-min gap in the data collection. All data collected during these two periods were summarized in 5-min time increments.

To determine how the travel patterns were changed by closing a ramp, 12 volume counters were placed on the arterial streets throughout the area (Fig. 1). These counters were placed so that only the northbound and eastbound traffic was counted on the north-south and east-west arterials, respectively. Preliminary observations indicated that the greatest changes in traffic flow would occur in these directions during the evening peak hour.

The travel time on all arterials and freeways in the study area was measured by making speed and delay runs. The data obtained on each run were overall travel time, total running time (time that vehicle was actually moving), total delay time and cause of each delay, overall travel speed, and running speed. Travel time information was obtained for each 0.2-mi increment and then compiled between each major intersection and for the total trip.

Using the data obtained with the speed and delay studies and the total hourly volume counts, the total vehicle-minutes of travel time was computed for all vehicles in the study area during each ramp condition on the freeway.

Time-lapse photography was used to collect the data at the four study locations on the freeway. Figure 2 shows a typical field location of the camera. On the freeway stripes painted of alternate dark and light colors and spaced at 50-ft intervals can be seen. All camera setups were located on overhead bridges.

The film was analyzed by projecting it with a time and motion study projector onto a screen having a grid to the same scale as that of each study location. Vehicle speeds were obtained by measuring the distance of movement of a vehicle for a specified num-

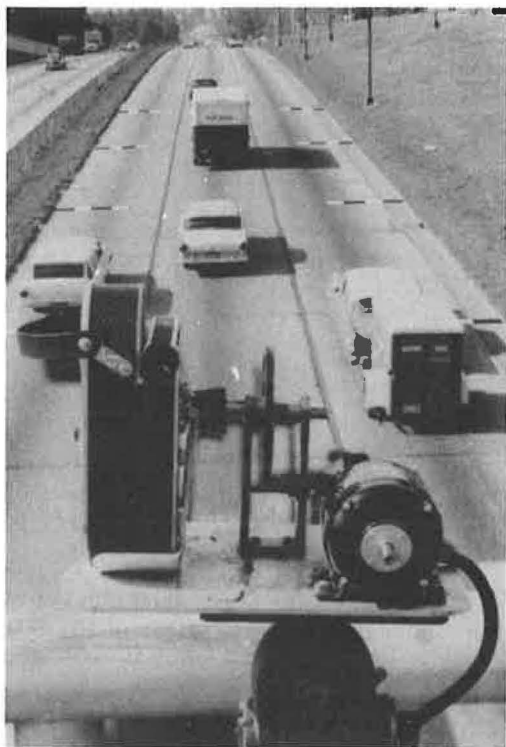


Figure 2. Field location of time-lapse movie camera at 10th Street, looking north.



Figure 3. Method of closing 10th Street northbound on-ramp, viewed from Williams Street.

ber of frames of movie film and dividing this distance by the time required for the vehicle to move between the frames of film measured.

The following information was collected for each location studied:

1. Vehicle volume.
2. Vehicle speeds.
3. Classification of vehicles into passenger car, single unit truck, semitrailer truck, and bus.

This information was collected in 5-min increments of time. By using the frame counter on the projector, each 5-min increment could be determined by counting off each 500-frame interval. These data were collected for each lane on the freeway. Volume and classification of vehicles were also obtained for the ramp.

A systematic sample of 20 vehicles was taken for each 5-min period to determine average speed for each lane for this time period. Statistical analysis based on sample survey theory indicated that a sample of this size was sufficient to give the true average speed within 2 mph 95 percent of the time.

Figure 3 shows a typical method of closing an on-ramp.

DATA ANALYSIS

To analyze the data obtained, it was necessary to take the initial information (such as vehicle volume and vehicle speeds) from the film and refine these data into a usable form. The film was divided into 5-min time intervals for each of the four study locations or positions. The following information was evaluated from the time-lapse movies:

1. Lane volumes (after ramp entrance).
2. Lane speeds.
3. Lane density (after ramp entrance).
4. Average lane volume (after ramp entrance).
5. Average lane speeds (after ramp entrance).
6. Average lane density (after ramp entrance).
7. Ramp volume.
8. Total volume.

The cameras were located on bridges passing over the North Freeway at North Avenue, 5th Street, 10th Street, and 14th Street. The bridges located at North Avenue, 10th Street, and 14th Street were interchange structures and the bridge located at 5th Street was a grade separation structure only.

TABLE 2
RANK ORDER OF FREEWAY VOLUMES AND SIGNIFICANT
DIFFERENCES OF STUDY POSITIONS

Ramp Condition	Rank Order of Freeway Volumes ¹			
	Lowest	2nd Lowest	2nd Highest	Highest
Normal operation	5th St.	North Ave.	10th St.	14th St.
North Ave. closed	North Ave.	5th St.	10th St.	14th St.
10th St. closed	10th St.	5th St.	North Ave.	14th St.
14th St. closed	5th St.	North Ave.	10th St.	14th St.

¹ No significant differences in those positions underlined together; significance according to Duncan (3).

In addition to the four study locations already described, a fifth study point located at the Peachtree Interchange was used to gather data; however, these data were not used in the analysis. Figure 1 shows the location of all study locations.

To determine the total overall travel time in vehicle-minutes which accrued in the study area, the major street system and the freeway in the study area were divided into links. Each of these links consists of a portion of a street between two other major streets or a portion of the freeway between interchanges. By multiplying the vehicle volumes by the respective travel times, the total number of vehicle-minutes was computed for each link. With the total travel time on each link available, the total travel time on each arterial street, freeway, and ramp in the study area was obtained.

Analysis of variance methods was used to analyze the data. Mathematical models were formulated in terms of the unknown parameters and the associated random variable. The quantitative physical characteristics (dependent variables) of interest in this study are the following:

1. Volume.
2. Speed.
3. Density.
4. Total travel time in system (in vehicle-minutes).
5. Total travel distance in system (in vehicle-miles).
6. Overall running speed.
7. Overall travel speed.

The independent variables of interest are as follows:

1. Ramp condition (that is, ramp open or closed).
2. Position (that is, position or location of a ramp on freeway).
3. Lane number.
4. Day.
5. Street.
6. Replication (in this case, each 5-min time interval).

In carrying out the analysis of variance of the data, a 10 percent level of significance was used for testing the variables.

Freeway Volumes

The volumes obtained for various ramp conditions and positions are shown in Figures 4 and 5. It is evident that the volume increases in the direction of travel along the freeway.

Table 2 gives the rank order and significant differences of the volumes at study positions under each ramp condition. Table 3 gives the rank order and significant

TABLE 3

**RANK ORDER OF FREEWAY VOLUMES AND SIGNIFICANT DIFFERENCES
OF RAMP CONDITIONS AT EACH STUDY LOCATION**

Study Location	Rank Order of Freeway Volumes ¹			
	Lowest	2nd Lowest	2nd Highest	Highest
North Ave. 14th St. closed	<u>North Ave. closed</u>	<u>10th St. closed</u>	<u>Normal operation</u>	<u>10th St. closed</u>
5th St. 14th St. closed	<u>North Ave. closed</u>	<u>Normal operation</u>	<u>10th St. closed</u>	<u>Normal operation</u>
10th St. 10th St. closed	<u>14th St. closed</u>	<u>North Ave. closed</u>	<u>Normal operation</u>	<u>Normal operation</u>
14th St. 10th St. closed	<u>Normal operation</u>	<u>14th St. closed</u>	<u>North Ave. closed</u>	<u>Normal operation</u>

¹ No significant differences in those positions underlined together; significance according to Duncan (3).

TABLE 4

**RANK ORDER OF FREEWAY SPEEDS AND SIGNIFICANT
DIFFERENCES OF STUDY LOCATIONS**

Ramp Condition	Rank Order of Freeway Speeds ¹			
	Lowest	2nd Lowest	2nd Highest	Highest
Normal operation	<u>14th St.</u>	<u>10th St.</u>	<u>5th St.</u>	<u>North Ave.</u>
North Ave. closed	<u>14th St.</u>	<u>10th St.</u>	<u>North Ave.</u>	<u>5th St.</u>
10th St. closed	<u>14th St.</u>	<u>10th St.</u>	<u>North Ave.</u>	<u>5th St.</u>
14th St. closed	<u>14th St.</u>	<u>10th St.</u>	<u>5th St.</u>	<u>North Ave.</u>

¹ No significant differences in those positions underlined together.

differences of ramp conditions at each study position. This is also shown in Figure 4.

Freeway Speeds

The speeds obtained for various ramp conditions and positions are shown in Figures 4 and 5. These figures show that the speed decreases in the direction of travel along the freeway as the volume increases. Figure 4 shows that the speeds tend to be higher and more constant when the 14th Street northbound on-ramp is closed. These figures also show that the lowest speeds occur when the freeway is operating normally with all ramps open.

Table 4 gives the rank order and significant differences of the speeds at study positions under each ramp condition. Table 5 gives the rank order and significant differences of ramp conditions at each study position. These data are also shown in Figure 4.

Freeway Densities

The densities obtained for various ramp conditions and positions are shown in Figures 4 and 5. The density increases sharply as the volume increases in the direction of travel along the freeway. Figure 4 shows that the density along the freeway is most constant when the 14th Street northbound on-ramp is closed. Also, the highest densities occur when the freeway is operating with all ramps open.

Table 6 gives the rank order and significant differences of the densities along the

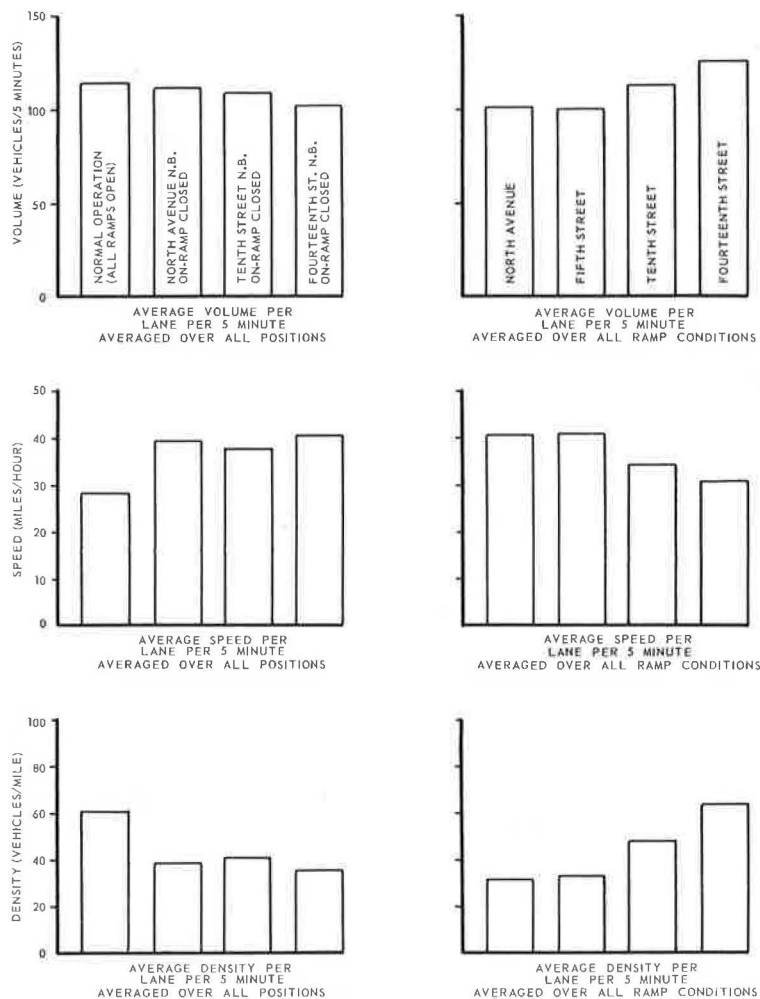


Figure 4. Average volume, speed, and density per lane per 5-min time interval on North Freeway averaged over all positions and ramp conditions.

freeway at study positions under each ramp condition. This table shows that when the 14th Street northbound on-ramp is closed the densities obtained at North Avenue, 5th Street, 10th Street, and 14th Street are constant.

Table 7 gives the rank order and significant differences of ramp conditions at each study position. These data are also shown in Figure 4.

Speed and Delay

The speed and delay studies that were made on the freeway verified the results obtained from the analysis of the time-lapse movie data. The speed and delay studies were analyzed in several different ways. The overall travel and running speeds were analyzed on the North Freeway, Northeast Freeway, Northwest Freeway, North and Northeast Freeways combined, and the North and Northwest Freeways combined. The overall travel and running speeds were computed on each freeway between the limits of the study area.

The analysis of overall travel and running speeds on the North Freeway indicates a significant difference in speeds between ramp conditions. The rank order of both over-

TABLE 5

RANK ORDER OF FREEWAY SPEEDS AND SIGNIFICANT DIFFERENCES
OF RAMP CONDITIONS AT EACH STUDY LOCATION

Study Location	Rank Order of Freeway Speeds ¹			
	Lowest	2nd Lowest	2nd Highest	Highest
North Ave.	Normal operation	North Ave. closed	10th St. closed	14th St. closed
5th St.	Normal operation	14th St. closed	10th St. closed	North Ave. closed
10th St.	Normal operation	10th St. closed	North Ave. closed	14th St. closed
14th St.	Normal operation	10th St. closed	North Ave. closed	14th St. closed

¹No significant differences in those positions underlined together.

TABLE 6

RANK ORDER OF FREEWAY DENSITIES AND SIGNIFICANT
DIFFERENCES AT STUDY LOCATIONS

Ramp Condition	Rank Order of Freeway Densities ¹			
	Lowest	2nd Lowest	2nd Highest	Highest
Normal operation	North Ave.	5th St.	10th St.	14th St.
North Ave. closed	5th St.	North Ave.	10th St.	14th St.
10th St. closed	5th St.	North Ave.	10th St.	14th St.
14th St. closed	North Ave.	5th St.	10th St.	14th St.

¹No significant differences in those positions underlined together.

all travel and running speeds from lowest to highest was normal operation, North Avenue and 10th Street on-ramp closed in any order, and 14th Street on-ramp closed. Similar results were also obtained for the Northeast and Northwest Freeways located in the study area.

When the overall travel and running speeds were combined for the freeways, there were no significant differences in the speeds under any of the ramp conditions. In this case combining of the freeways and computing travel and running speeds increases the variability of the speeds to the point where significant differences are not detectable.

The speed and delay studies that were made on the surface streets were analyzed in two ways. The east-west streets were grouped for analysis, as well as the north-south streets. Analysis of the east-west streets showed that the overall running speed is not significantly different between ramp conditions, as indicated by the analysis of variance, but there is a significant difference in the ramp-day interaction term. There is a significant difference in overall running speeds between streets. Days in this case are significantly different. The ramp-street and the ramp-day interaction terms are significant and indicate that some ramp conditions influence the running speed on the freeway on some days and not on others.

The analysis of the speed and delay data obtained on the north-south streets show similar results for both the overall travel and running speeds. These speeds were found to be significantly different between ramp conditions and streets. Neither the days nor any of the interaction terms were significant on the north-south streets and this condition indicates that the speeds were only influenced by ramp conditions and the streets.

The most important information contained in the analysis of the speed and delay studies made on the streets in the study system was that significant differences in overall

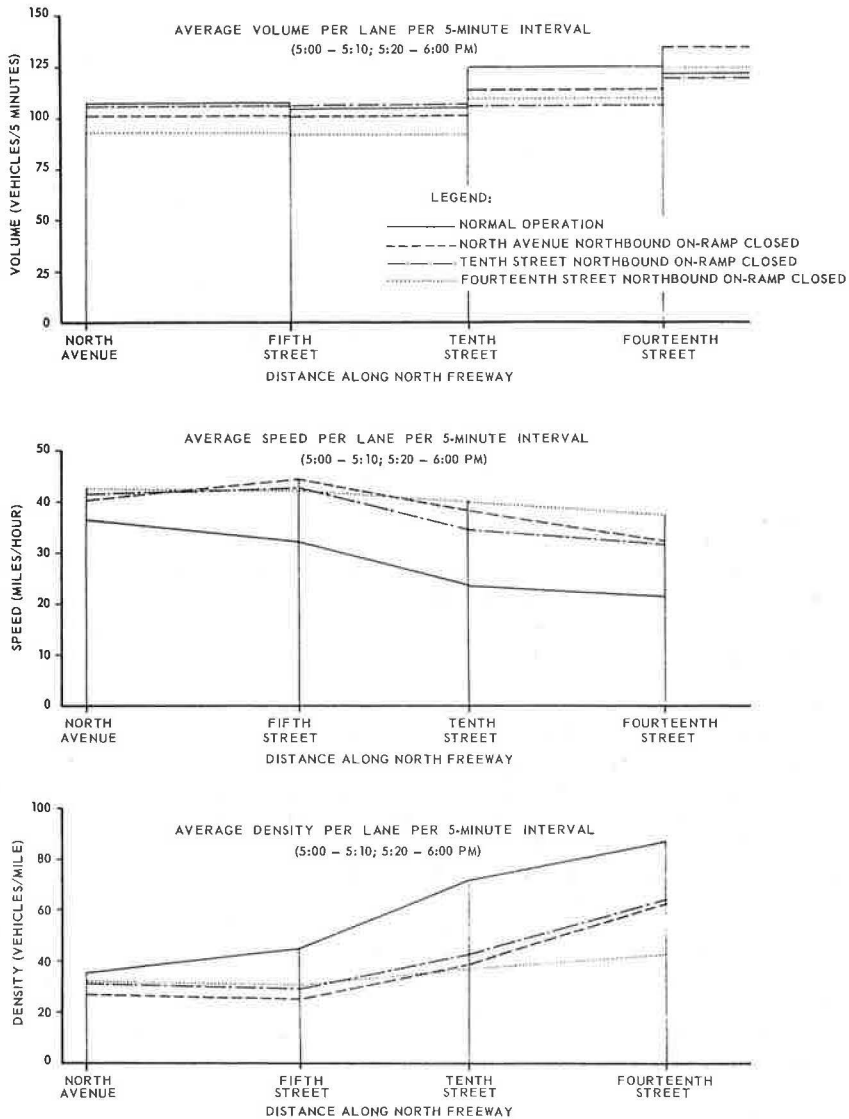


Figure 5. Average volume speed, and density per lane per 5-min time interval on North Freeway.

and running speeds were detectable for various ramp conditions. The travel time on a particular street is inversely proportional to the travel speed. Therefore, as the travel speeds are changed, the total overall travel time within the entire system is influenced. It is of no great importance that the analysis indicated significant difference in speeds between streets, because these differences existed before any ramp conditions were varied. One would expect, for example, the overall and running speeds on various streets to be different because of different signal systems, parking requirements, geometric design, etc., found on the various streets.

Surface Street Volumes

The volumes on the north-south and east-west streets were analyzed in the same manner as the speed and delay studies. The volumes between 4:00 and 5:00 PM were considered separately from the volumes between 5:00 and 6:00 PM. The analysis of

TABLE 7

RANK ORDER OF FREEWAY DENSITIES AND SIGNIFICANT DIFFERENCES OF RAMP CONDITIONS AT EACH STUDY LOCATION

Study Location or Position	Rank Order of Freeway Densities ¹			
	Lowest	2nd Lowest	2nd Highest	Highest
North Ave.	North Ave. closed	10th St. closed	14th St. closed	Normal operation
5th St.	North Ave. closed	10th St. closed	14th St. closed	Normal operation
10th St.	14th St. closed	North Ave. closed	10th St. closed	Normal operation
14th St.	14th St. closed	North Ave. closed	10th St. closed	Normal operation

¹ No significant differences in those positions underlined together.

data obtained for the east-west streets showed the same results for each time period that was analyzed. The volumes were significantly different on the east-west streets between ramp conditions and streets. The ramp-street interaction term was the only interaction term that was significant and indicates that some ramp conditions significantly change the volumes on some streets more than on others. That is, when a specified ramp is closed, traffic that would normally use the ramp is diverted to another ramp via the surface streets or the traffic may be diverted to use of the street system entirely.

The analysis of the volumes on the north-south streets indicated different results for each time period that was analyzed. The analysis of the volumes on the north-south streets between 4:00 and 5:00 PM indicated that the significant factors were ramp condition, position, street, and day. The interaction terms that were significant were ramp-position, ramp-street, ramp-day, position-street and ramp-position-street. The analysis of the volumes on the north-south streets between 5:00 and 6:00 PM indicated that the significant factors were ramp condition, position, street, and day. The interaction terms that were significant were ramp-position, ramp-street, ramp-day, position-street, position-day, street-day, ramp-position-street, ramp-position-day, and ramp-street-day. These results indicate that some of the ramp conditions influence the volumes on some of the streets at some of the positions and not at other positions. In other words, when a particular ramp is closed, traffic that would normally use the ramp is diverted to another ramp via the surface streets or this traffic may be diverted entirely to the surface street.

Total Overall Travel Time

The lowest overall travel time expressed in vehicle-minutes for the entire system occurred under normal operation of the freeway, and closing of any one of the on-ramps significantly increased travel time. The significantly highest travel time occurred when the 14th Street on-ramp was closed as is given in Table 8. However, based on uniformity of speed and density, optimum operation of the North Freeway occurred when this ramp is closed. The ramp closings at North Avenue and 10th Street also improved the operation of the freeway compared to normal operation; however, this improvement was not as great as the improvement that occurred when the 14th Street on-ramp was closed.

Total Travel

The total travel on the freeways and streets expressed in vehicle-miles was analyzed in the same manner as the speed and delay studies and the overall travel time. These results indicate that with the exception of closing the 14th Street northbound on-ramp, total overall travel in the system is not significantly influenced by the various ramp conditions. However, significant differences in travel occur on specific streets and

TABLE 8
TOTAL OVERALL TRAVEL TIME ON FREEWAYS AND SURFACE STREETS IN STUDY AREA
IN VEHICLE-MINUTES (FROM 5:00 TO 6:00 PM FOR VEHICLES TRAVELING
IN THE NORTHBOUND AND WESTBOUND DIRECTION)

Street	Day	Travel Time (vehicle-minutes)			
		Normal Operation (All Ramps Open)	North Avenue Northbound On-Ramp Closed	10th Street Northbound On-Ramp Closed	14th Street Northbound On-Ramp Closed
North-south:					
Peachtree	1	10,719	15,196	20,073	34,723
	2	11,450	13,692	23,355	26,220
	3	15,058	13,016	16,589	19,848
West Peachtree	1	7,922	10,041	16,389	8,072
	2	8,192	9,199	9,646	12,103
	3	10,234	12,107	6,666	10,017
Spring	1	6,796	14,214	12,588	13,498
	2	7,834	8,678	8,516	8,526
	3	7,343	13,010	11,095	8,785
Hemphill- Northside Drive	1	7,840	10,824	9,583	11,807
	2	7,227	10,687	8,544	8,998
	3	8,492	10,194	11,172	13,343
Subtotal	1	33,277	50,275	46,618	68,100
	2	34,703	42,256	50,061	55,847
	3	41,127	48,327	45,522	52,043
East-west:					
North Avenue	1	3,200	3,912	3,056	3,422
	2	5,087	6,279	2,840	3,958
	3	3,513	4,305	5,705	3,906
10th Street	1	2,753	3,226	2,292	4,401
	2	1,727	4,239	2,492	3,771
	3	1,341	3,794	2,758	3,331
14th Street	1	1,735	4,368	8,750	2,980
	2	3,328	10,006	6,725	2,648
	3	3,030	5,747	3,786	4,021
Subtotal	1	7,688	11,506	14,098	10,803
	2	10,142	20,524	11,057	10,377
	3	7,884	13,846	12,249	11,258
Freeway:					
North	1	13,315	11,677	9,452	8,535
	2	17,312	11,520	11,565	9,060
	3	13,978	12,765	17,467	10,205
Northeast	1	4,070	4,787	3,933	5,564
	2	5,743	5,184	2,529	4,377
	3	4,234	5,960	10,221	2,924
Northwest	1	3,948	2,948	2,534	2,866
	2	2,694	2,759	2,509	2,748
	3	3,084	2,840	2,554	2,815
Ramps	1	1,311	1,897	2,405	1,944
	2	2,439	2,393	2,290	2,142
	3	1,498	2,708	2,358	1,543
Subtotal	1	22,644	21,309	18,324	18,909
	2	28,188	21,856	18,893	18,327
	3	22,794	24,273	32,600	17,487
Total	1	63,609	83,090	79,040	97,812
	2	73,033	84,636	80,011	84,551
	3	71,805	86,446	90,371	80,788

sections of the freeway within the system in the study area. Such changes should be expected, and Table 9 gives those individual streets and sections of the freeway where significant changes may occur.

RESULTS

The results of the analysis of the data collected on this study can be summarized as follows:

TABLE 9

TOTAL OVERALL TRAVEL ON FREEWAYS AND SURFACE STREETS IN STUDY AREA
IN VEHICLE-MILES (FROM 5:00 TO 6:00 PM FOR TRAVEL IN THE
NORTHBOUND AND WESTBOUND DIRECTION)

Speed	Day	Overall Travel (vehicle-miles)			
		Normal Operation (All Ramps Open)	North Avenue Northbound On-Ramp Closed	10th Street Northbound On-Ramp Closed	14th Street Northbound On-Ramp Closed
North-south:					
Peachtree	1	2,333	2,309	2,721	2,728
	2	2,628	2,183	2,733	2,578
	3	2,643	2,002	2,650	2,861
West Peachtree	1	1,672	1,419	1,838	1,620
	2	1,573	1,444	1,853	1,254
	3	1,635	1,475	1,529	1,613
Spring	1	1,516	1,539	1,634	1,335
	2	1,576	1,452	1,673	1,180
	3	1,493	1,463	1,547	1,362
Hemphill- Northside Drive	1	2,620	2,620	2,620	2,620
	2	2,620	2,620	2,620	2,620
	3	2,762	2,762	2,762	2,762
Subtotal	1	8,141	7,887	8,813	8,303
	2	8,397	7,699	8,879	7,632
	3	8,533	7,702	8,488	8,598
East-west:					
North Avenue	1	448	604	454	427
	2	511	628	459	496
	3	502	578	467	483
10th Street	1	355	508	435	430
	2	323	590	434	409
	3	311	600	453	463
14th Street	1	429	715	521	542
	2	481	757	514	591
	3	618	704	640	658
Subtotal	1	1,232	1,827	1,410	1,399
	2	1,315	1,975	1,407	1,496
	3	1,431	1,882	1,460	1,604
Freeway:					
North	1	6,601	6,788	6,462	5,945
	2	6,604	6,664	6,338	5,767
	3	6,603	6,739	6,401	5,859
Northeast	1	1,980	2,182	1,995	2,023
	2	1,634	2,074	2,023	1,995
	3	1,814	2,146	2,005	2,005
Northwest	1	2,709	2,348	2,043	2,201
	2	2,081	2,296	1,985	2,188
	3	2,383	2,289	2,021	2,201
Ramps	1	278	248	243	239
	2	273	252	257	253
	3	275	249	251	246
Subtotal	1	11,568	11,566	10,743	10,408
	2	10,592	11,286	10,603	10,203
	3	11,075	11,423	10,678	10,311
Total	1	20,941	21,280	20,966	20,110
	2	20,304	20,960	20,889	19,331
	3	21,039	21,007	20,726	20,513

1. Considering all positions, the highest volumes on the North Freeway occurred with the freeway operating normally and the significantly lowest volumes occurred with the 14th Street and 10th Street northbound on-ramps closed. The volumes obtained with the 10th Street and 14th Street northbound on-ramps closed were not significantly different from each other.

2. The traffic volumes between the four study locations increased as one moved north on the North Freeway from North Avenue to 14th Street. However, the volumes

that occurred at North Avenue and 5th Street were not significantly different from each other.

3. The speed on the North Freeway decreased significantly under all ramp conditions as one moves north on the freeway from North Avenue to 14th Street. The speeds on the freeway under conditions of a ramp closure were significantly higher than the speed obtained with the freeway operating normally. There was no significant difference in speeds under ramp closure conditions.

4. The speeds on the North Freeway under all ramp conditions were significantly lower at 14th Street than any of the other positions. The speeds that occurred at North Avenue and 5th Street were not significantly different from each other under ramp closure conditions but were significantly different from normal operation. The speeds at North Avenue and 5th Street were significantly higher than the speeds at the other positions under all ramp conditions.

5. The density on the freeway generally increases significantly as one moves north on the North Freeway from North Avenue to 14th Street. Considering all positions together, the density on the North Freeway is significantly higher with normal operation. The density on the freeway with any of the on-ramps closed is significantly lower than the density with normal operation.

6. Closing any one of the northbound on-ramps to the North Freeway at North Avenue, 10th Street, and 14th Street resulted in a more uniform and smoother flow of traffic on the freeway as reflected by the speeds and densities on the freeway. The most desirable operation occurred when the 14th Street on-ramp was closed.

7. The speed and delay studies on the east-west and north-south streets show that closing any one of the on-ramps to the North Freeway influences both the travel and running speeds on the surface streets. The speeds were increased and decreased significantly or remained unchanged, depending on the particular street and the ramp condition.

8. The analysis of the volumes on the east-west and north-south streets shows that closing any one of the on-ramps to the North Freeway influences the volumes on the streets.

9. The total overall travel time expressed in vehicle-minutes on the North Freeway with the 14th Street on-ramp closed was significantly lower than the total travel time on the freeway under any other ramp condition. The total overall travel time on the freeway under all ramp conditions except the 14th Street on-ramp closure was not significantly different from each other.

10. The total overall travel time expressed in vehicle-minutes in the study area under normal operation was significantly lower than the total travel time with any of the ramp closure conditions. Significantly highest overall travel time occurred when the 14th Street on-ramp was closed.

11. Closing the 14th Street northbound on-ramp on the North Freeway decreased the total overall travel expressed in vehicle-miles significantly from the travel that occurred with normal operation of the Freeway. The total travel that occurred with the other ramp closures was not significantly different from the total travel which occurred with normal operation of the freeway.

12. Significant changes in overall travel time and travel on various streets and sections of the freeway occurred under various ramp conditions. These changes are generally reflected by an increase in congestion and delay on streets which served ramps before and ahead of a ramp that was closed. Congestion and delay on streets served by ramps that were closed was reduced and is reflected by a general decrease in travel time and travel on these streets.

CONCLUSIONS

The following conclusions were determined from analysis of the data:

1. The number of on-ramps on a given section of the Atlanta Freeway influenced operation of the freeway. When one of these ramps was eliminated by closing it, improved operation of the freeway was indicated.

2. The increased speeds on the freeway with any of the on-ramps closed are apparently caused by the following factors:

- a. Elimination of the short weaving section on the North Freeway between 14th Street and the junction of the Northeast and Northwest Freeways by closing the on-ramp at 14th Street and an increase in weaving distances for other ramp closure conditions.
 - b. Removal of an intersection conflict when an on-ramp is closed.
 - c. "Metering" the flow of traffic entering the freeway by reducing the number of ingress points.
3. The number and location of on-ramps to the freeway influences the operation of the surface street system which serves the freeway.
4. For this study, minimum overall travel time for the freeway and surface streets within the study area was obtained under normal operation of the freeway. Closing any one of the on-ramps increased overall travel time within the study area. However, as indicated by the first conclusion, operation of the freeway was improved by closing any one of the ramps.
5. Problems of congestion and delay are created on the surface streets serving ramps before and ahead of a particular ramp that is closed.
6. Time-lapse movie photography is an effective, reliable, and economical method to collect simultaneously volume, speed, and density data at several different locations on a freeway, using a minimum number of personnel.
7. Studying simultaneously the volume, speed, and density at several different locations on a freeway with variable ramp spacings will give a more reliable indication of the true traffic flow characteristics that exist on the freeway under variable ramp spacings than a point study at a particular location where the ramp is closed.

RECOMMENDATIONS

1. Considering the operation of the freeway, it is recommended that interchanges be spaced as far apart as possible consistent with the effective operation of the freeway and the arterial street system serving the freeway.
2. It is recommended that the northbound on-ramp to the North Freeway at 14th Street be closed during the weekday afternoon peak periods between the hours of 4:30 and 6:00 PM for a test period of 3 months. This procedure would permit an extensive study to be made of the effect of traffic engineering changes on the arterial street system influenced by this ramp closure on reducing total travel time and yet maintaining the improvement in freeway operation observed when this ramp was closed.
3. It is further recommended that an extensive study be carried out of the city street system serving the freeways to determine what changes can be made in the street system to improve traffic flow with the 14th Street northbound on-ramp closed.
4. In making any further studies of this nature, it is recommended that the study be made on both a system and a subsystem basis; that is, studies should be made on both the freeways and the city streets serving the freeways.

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