Influence of Off-Ramp Spacing on Traffic Flow Characteristics on Atlanta Freeway and Arterial Street System

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The spacing of interchanges on freeways can have a pronounced effect on the operating efficiency of a freeway in a downtown area and can therefore affect the entire transportation system within a city. Proper spacing of interchanges on freeways is also important from a cost and a vehicle-time viewpoint. The purpose of this study was to determine the influence of off-ramp spacing on the operational characteristics of the Atlanta Freeway System and the city streets influenced by the Freeway.

The southbound off-ramps at 14th St., 10th St., and North Ave. were closed for a period of two weeks each during the morning peak traffic period. During these closures and during normal operations, time-lapse movie photography was used to collect data at four locations along the Freeway. Speed and delay studies were made on the freeways and surface streets during each ramp closure and during normal operation of the Freeway.

Analysis of variance techniques were used to make comparisons of volumes, speeds, densities, over-all travel, and over-all travel time data observed on all the streets and freeways within the system.

It was found that closing any one of the southbound off-ramps on the North Freeway during the morning peak hour caused little or no improvement in the over-all operating characteristics of the Freeway. When a significant change was noted, it was usually a reduction in the quality of traffic flow.

As a result of this study, it was found that off-ramps leading to the central business district of a city should be spaced as close together as possible, consistent with design factors and the ability of the surface streets in the vicinity of the off-ramp to accommodate the traffic flow from the ramp.

•THE PURPOSE of this research was to determine the influence of off-ramp spacing on the traffic flow characteristics on the Atlanta Freeway System and city streets influenced by the Freeway. This is the second phase of a study 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.

The first phase was concerned with the influence of on-ramp spacing on the traffic flow characteristics on the Atlanta Freeway System and city streets influenced by the Freeway.

In the first phase it was found that lengthening the spacing by closing any one of the northbound on-ramps (by closing an on-ramp) on the North Freeway during the afternoon peak hour improved the over-all 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 observed on the Freeway. It was also found that increasing the spacing of on-ramps caused a significant increase in the total travel time in vehicle-minutes within the entire system. The over-all travel in vehicle-miles was not changed significantly by closing any one of the northbound on-ramps within the system.

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DATA COLLECTION

The study area (Fig. 1) for this phase of the research lies north of the central business district of Atlanta. It was chosen because any alterations or changes in ramp spacing would influence traffic flow conditions in this area. Changes in traffic flow outside this area would be rather small and the methods used to detect changes in conditions would not be sensitive enough to measure this change.

The land use in this area consists mainly of small business, apartment houses, boarding houses, insurance offices, small and medium size hotels, service stations, old residences, and schools. The majority of traffic in the study area during the morning peak hour is traffic which is destined to or is passing through rather than originating in the area.

The street system consists of three east-west arterials and five arterials running generally in a north-south direction. The Freeway runs generally north-south near the center of the study area. The southbound off-ramps exit from the North Freeway at 14th St., 10th St., North Ave., and Williams St.

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 Northwest and Northeast Freeways. From this junction north, to both the Northwest and Northeast Freeways, it consists of two 12-ft lanes in each direction. The Freeways and ramps have a concrete surface, and the concrete on the ramps has been darkened to provide color contrast.

The interchanges on the North Freeway at 14th St., 10th St., and North Ave. are of diamond-type design with the off-ramps exiting directly from the Freeway with no deceleration lanes provided. The Williams St. off-ramp exits directly from the Freeway onto Williams St., again with no deceleration lane provided on the Freeway. Fifth St. is a grade separation only, not an interchange.

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 horizontal curve used was 3 deg and the maximum vertical grade used was 5 percent.

The method used for varying the ramp spacing was to close certain ramps during the peak period of flow. This method allowed the ramp spacing to be altered without making permanent or semi-permanent changes in the Freeway and ramps. When a ramp was closed, the interchange was effectively eliminated from the system and the ramp spacing of the "remaining interchanges" was changed. The distances between interchanges are given in Table 1. Each of the southbound off-ramps located at 14th St., 10th St., and North Ave. was closed during the morning peak peak period between 7:00 and 9:00 AM for a period of two weeks. The ramps were closed on the following dates: 14th St. — April 2-6, 9-13, 1962 (Monday through Friday of each week); 10th St. — April 23-27, April 30-May 4, 1962 (Monday through Friday of each week); and

TABLE 1

INTERCHANGE DISTANCES

Interchange	Distance (mi)			
	Normal Operation[1]	Southbound Off-Ramp Closed at		
		North Ave.	10th St.	14th St.
Peachtree Rd.	0.891	0.891	0.891	
14th St.	0.359	0.359		1.250
10th St.	0.708	0.997	1.067	0.708
North Ave.	0.189		0.189	0.189
Williams St.				

[1] All ramps open.

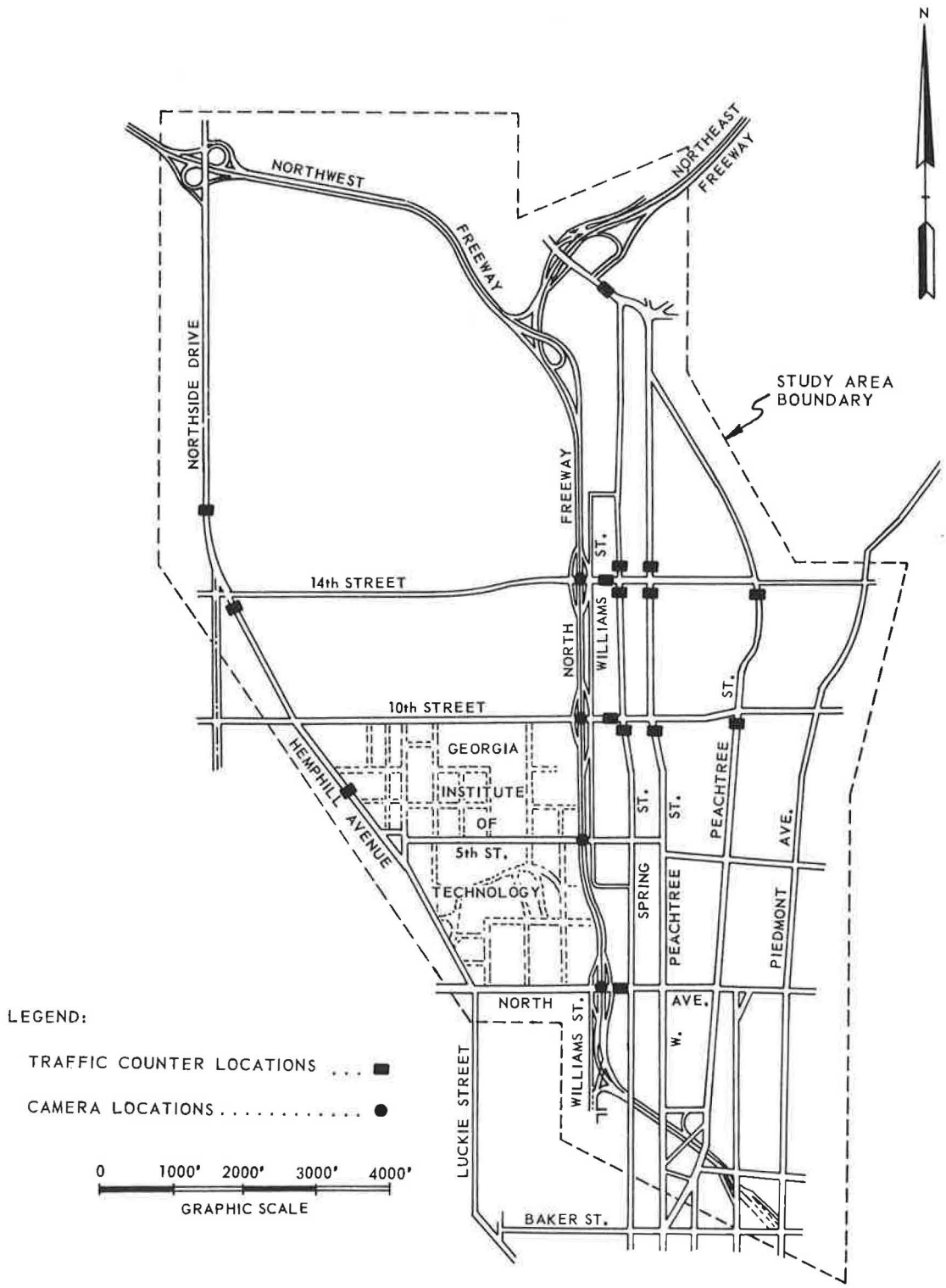

Figure 1. Study area.

Figure 2. Method of closing North Ave. southbound off-ramp.

North Ave. —May 14-18, 21-25, 1962 (Monday through Friday of each week). Each off-ramp was closed separately and only one ramp was closed at any one time. Table 1 gives the distance between interchanges for each ramp condition. Figure 2 shows a typical method of closing an on-ramp.

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

Studies were made at four different locations on the North Freeway under normal operation of the Freeway, and with the southbound off-ramp closed at 14th St., 10th St., and North Ave. The data collected at these locations were volume, speed, and density in each lane on the North Freeway and the ramp volume. These data were collected between 7:20 and 8:00 AM and between 8:10 and 8:50 AM by the use of time-lapse movie photography. The cameras used to make the movies would hold only enough film for 40 min of continuous filming when exposed at the filming rate of 100 frames per min. All data collected during these two periods were summarized in 5-min time increments.

Fifteen mechanical volume counters were placed on the arterial streets throughout the study area to determine how the travel patterns changed when a ramp was closed. Figure 1 shows the locations of these counters. The counters were placed such that only the southbound and eastbound traffic was counted on the north-south and east-west arterials, respectively. The assumption was made that the traffic flow in opposite directions would not be significantly affected by the ramp closures.

The travel time on all freeways and arterials within the study area was measured by the use of speed and delay studies. The data which were obtained from each speed and delay run were over-all travel time, total running time (time that vehicle was actually moving), total delay time and cause of each delay, over-all travel speed, and running speed. These data were summarized between major intersections and for the total trip.

The total vehicle-minutes of travel time were computed for all vehicles in the study area during each ramp condition on the Freeway by using the data obtained with the speed and delay studies and volume counts.

Time-lapse motion picture photography was used to collect data at the four study locations on the Freeway. Figure 3 shows a typical field setup with a camera on a bridge passing over the North Freeway at the study location, together with stripes of alternate dark and light color painted on the Freeway at 50-ft intervals.

The film was analyzed by projecting it with a time and motion study projector onto a screen having a grid which matched the lines painted on the pavement at each study

Figure 3. Field location of time-lapse movie camera at 10th St.

location. Vehicular speeds were obtained by measuring the distance of movement of a vehicle for a specified number of movie frames and dividing this distance by the time required for filming that specified number of movie frames.

Vehicle volumes and vehicle speeds per lane were collected from the movie film. From this data, the densities in each lane were computed. These data were summarized in 5-min increments of time. By the use of the final counter on the projector, each 5-min increment could be determined by counting each 500-frame interval. Volume data were also obtained for each off-ramp.

Average speed for each lane and for each 5-min period was determined by taking a systematic sample of 20 vehicles per 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.

ANALYSIS OF DATA

To analyze the data which were obtained it was necessary to take the raw data, such as vehicle volume and vehicle speeds, from the film and refine these data to a usable form. The film was divided into 5-min time intervals for each of the four study locations. The following information was evaluated from the time-lapse movie film: (a) lane volumes (before ramp entrance), (b) lane speeds, (c) lane densities (before ramp entrance), (d) average lane volumes (before ramp entrance), (e) average lane speeds (before ramp entrance), (f) average lane densities (before ramp entrance), (g) ramp volume, and (h) total volume.

The major street system and the Freeway in the study area were divided into links to determine the total over-all travel time in vehicle minutes and total travel in vehicle-

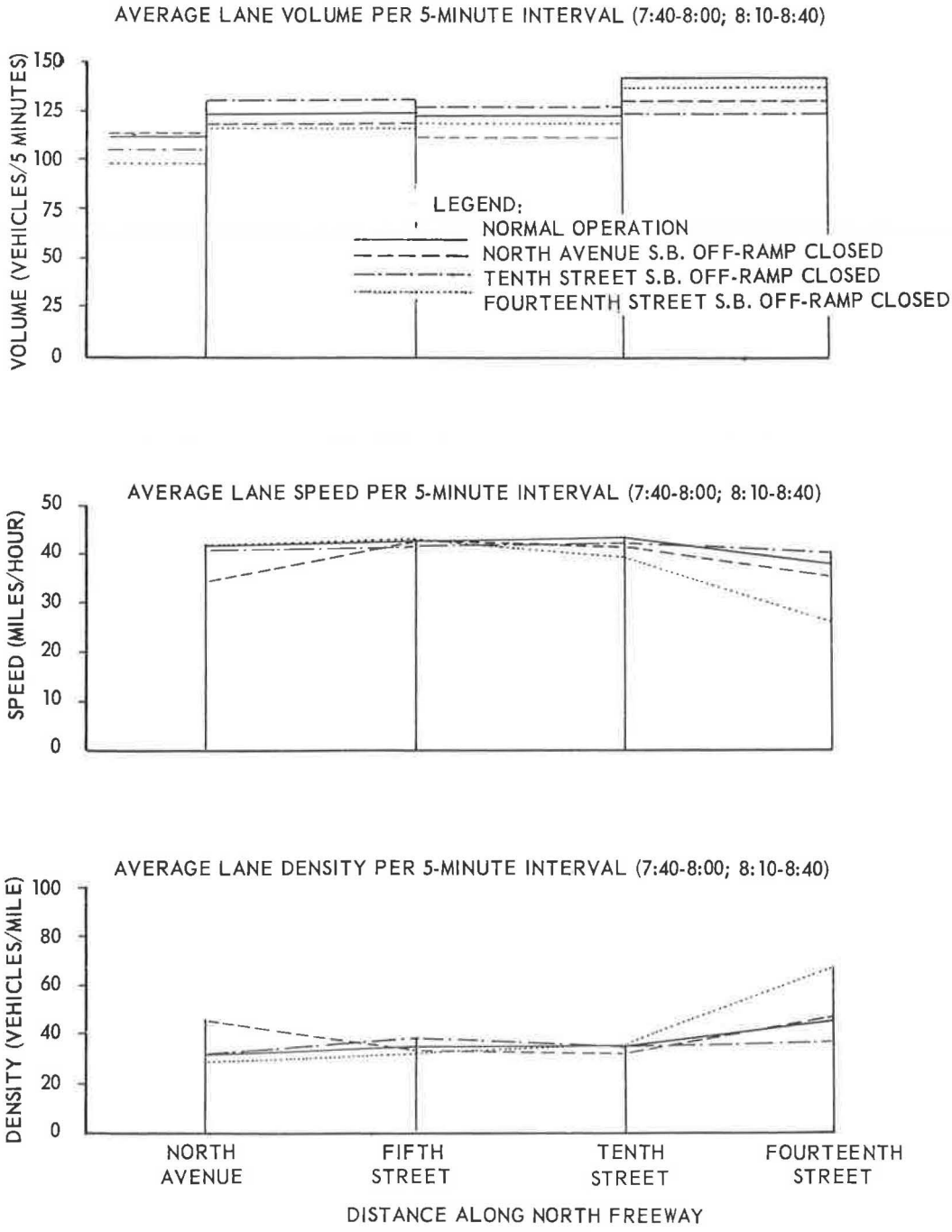

Figure 4. Average volume, speed, and density per 5-min interval on North Freeway.

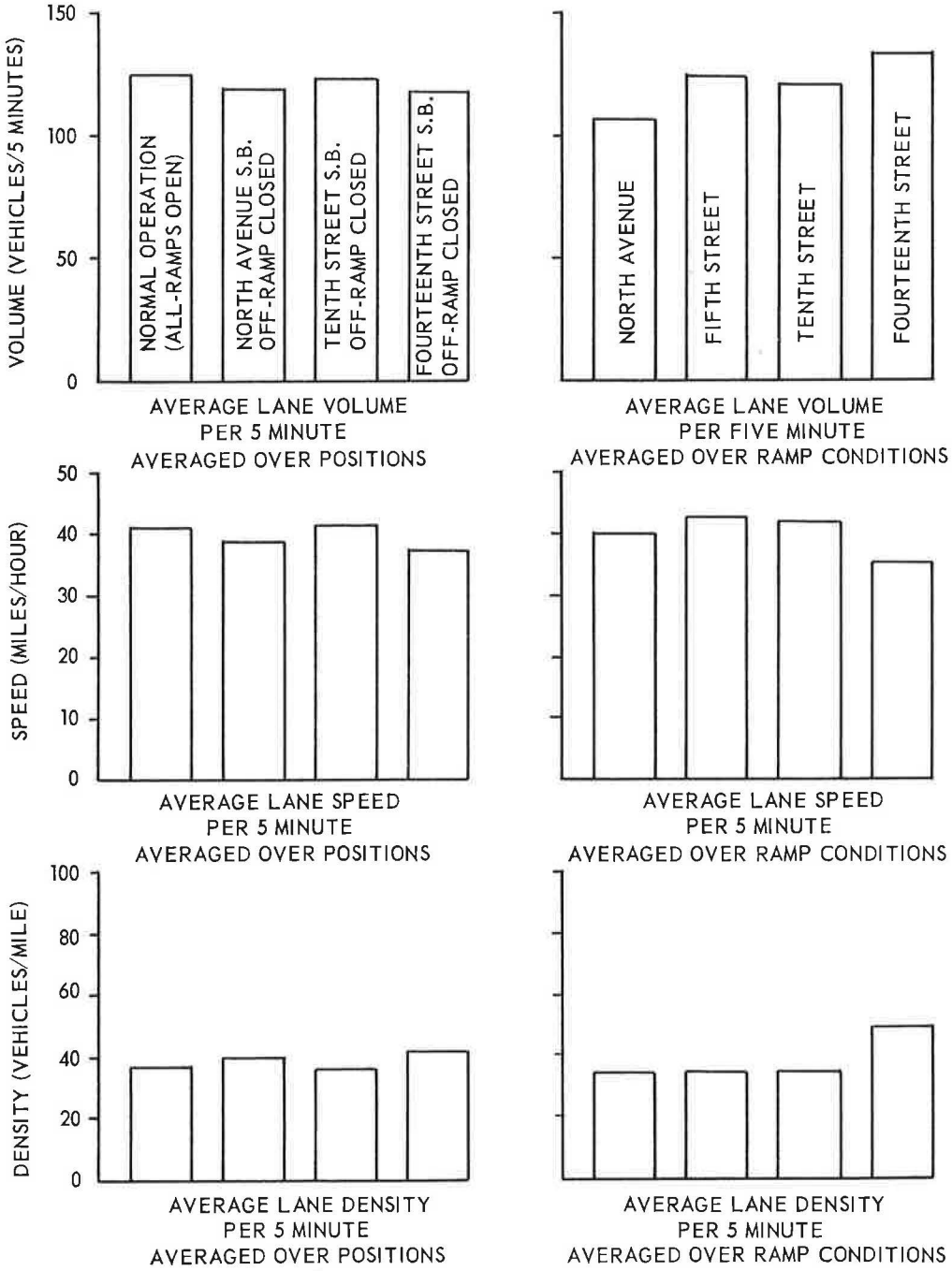

Figure 5. Average North Freeway traffic characteristics for 5-min interval.

TABLE 2

RANK ORDER OF FREEWAY VOLUMES AND SIGNIFICANT DIFFERENCES OF STUDY LOCATIONS[1]

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

[1] No significant differences in factors underlined together.

TABLE 3

RANK ORDER OF FREEWAY VOLUMES AND SIGNIFICANT DIFFERENCES IN RAMP CONDITIONS[1]

Study Location	Rank Order of Volume with Ramp Closed at			
	Lowest	2nd Lowest	2nd Highest	Highest
North Ave.	10th St.	14th St.	North Ave.	Normal
5th St.	14th St.	North Ave.	Normal	10th St.
10th St.	10th St.	North Ave.	14th St.	Normal
14th St.	14th St.	Normal	10th St.	North Ave.

[1] No significant differences in factors underlined together.

TABLE 4

RANK ORDER OF FREEWAY SPEEDS AND SIGNIFICANT DIFFERENCES OF RAMP CONDITIONS[1]

Study Location	Rank Order of Speed with Ramp Closed at			
	Lowest	2nd Lowest	2nd Highest	Highest
14th St.	14th St.	North Ave.	Normal	10th St.
10th St.	14th St.	North Ave.	10th St.	Normal
5th St.	10th St.	North Ave.	Normal	14th St.
North Ave.	North Ave.	10th St.	14th St.	Normal

[1] No significant differences in factors underlined together.

TABLE 5

RANK ORDER OF FREEWAY SPEEDS AND SIGNIFICANT DIFFERENCES OF STUDY LOCATIONS[1]

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

[1] No significant differences in factors underlined together.

miles which accrued during the peak hour. Each of these links consisted of a portion of a street between two other major streets or a portion of the Freeway between interchanges. The total number of vehicle-minutes was computed for each link by multiplying the vehicle volume by the respective travel times. The total travel time on each of the arterial streets, Freeways and ramps was obtained from the calculations of the link times.

Analysis of variance methods were used to analyze the data. Mathematical models were formulated in terms of the unknown parameters and the associated random variables. The dependent variables of interest in this study consist of the following: (a) volume, (b) speed, (c) density, (d) total travel time in system (expressed in vehicle-minutes), (e) total travel distance in system (expressed in vehicle-miles), (f) over-all running speed, and (g) over-all travel speed. The independent variables of interest in this study consist of the following: (a) ramp condition (ramp open or closed), (b) position (location of ramp along Freeway), (c) lane number, (d) day, (e) street, and (f) replication (replication is each 5-min time interval). The 10 percent level of significance was used for testing the variables in the analysis of the variance of the data.

FREEWAY VOLUMES

Figures 4 and 5 show that the volume decreases in the direction of travel along the Freeway. Figure 5 also shows that the highest volumes occur when the Freeway is operating normally with all ramps open.

Table 2 gives the rank order and significant differences of ramp conditions at each study location and Table 3 gives the rank order and significant differences of the volumes at study locations under each ramp condition. These data are represented graphically in Figure 4. The locations are underscored where the differences in volumes are not significant, according to Duncan's "Multiple Range and Multiple F Tests" (5).

The highest volumes generally occurred on the North Freeway when it was operating normally. The volumes observed under normal operations were significantly different from those observed when any off-ramp was closed. The volumes observed when any of the off-ramps were closed were not significant from each other, which is to say that no matter which off-ramp was closed, the volumes were significantly less than those which occurred under normal operation.

The traffic volumes decreased in magnitude as one moved southward along the North Freeway from 14th St. to North Ave., although the volumes observed at 10th St. and at 5th St. were not significantly different from each other.

FREEWAY SPEEDS

Figures 4 and 5 show that there were insignificant differences in the speeds at any one of the study locations or under any of the ramp conditions except at 14th St. with the 14th St. off-ramp closed and at North Ave. with the North Ave. off-ramp closed.

Table 4 gives the rank order and significant differences of ramp conditions at each location and Table 5 gives the rank order of speeds and significant differences of locations. These data are also shown graphically in Figure 4. The factors are again underscored where the differences are not significant.

The speed generally increased on the Freeway as one moved southbound along the North Freeway. The speeds observed at 14th St. were significantly lowest. The speeds at the other positions were not significantly different from each other.

When averaged over all the locations, the speeds were significantly lowest when the 14th St. off-ramp was closed. The highest speeds occurred when the 10th St. off-ramp was closed, but these speeds were not significantly different from those observed under normal operation of the Freeway.

FREEWAY DENSITIES

Figures 4 and 5 show that the density generally decreased as the volume decreased in the direction of travel southward along the Freeway. It can be noted from Figure 4

TABLE 6

RANK ORDER OF FREEWAY DENSITIES AND SIGNIFICANT DIFFERENCES OF RAMP CONDITIONS[1]

Study Location	Rank Order of Density with Ramp Closed at			
	Lowest	2nd Lowest	2nd Highest	Highest
14th St.	10th St.	North Ave.	Normal	14th St.
10th St.	No. Ave.	10th St.	Normal	14th St.
5th St.	14th St.	North Ave.	Normal	10th St.
North Ave.	14th St.	Normal	10th St.	North Ave.

[1] No significant differences in factors underlined together.

TABLE 7

RANK ORDER OF FREEWAY DENSITIES AND SIGNIFICANT DIFFERENCES OF STUDY LOCATIONS[1]

Ramp Condition	Rank Order of Density			
	Lowest	2nd Lowest	2nd Highest	Highest
Normal operation	North Ave.	5th St.	10th St.	14th St.
14th St. closed	5th St.	North Ave.	10th St.	14th St.
10th St. closed	10th St.	14th St.	5th St.	No. Ave.
North Ave. closed	10th St.	5th St.	North Ave.	14th St.

[1] No significant differences in factors underlined together.

that the density was least uniform and tended to be highest when the 14th St. and North Ave. off-ramps were closed. It may also be seen that the most uniform densities occurred when the Freeway was operating normally.

Table 6 gives the rank order of densities and significant differences of ramp conditions and Table 7 gives the rank order of densities and significant differences of study locations. Again the factors are underscored when the differences are not significant.

SPEED AND DELAY

The speed and delay studies which were made on the Freeway verified the results obtained from the analysis of the movie films. The speed and delay studies were analyzed in several different ways. The over-all travel and running speeds were analyzed on the North Freeway, Northeast Freeway, Northwest Freeway, North Northeast Freeways combined and the North and Northwest Freeways combined.

The over-all speeds and running speeds tended to be lowest on the North Freeway when the North Ave. off-ramp was closed, but speeds under this condition were not significantly different than when the 14th St. off-ramp was closed. The highest speeds occurred under normal operation, but these speeds were not significantly different from the speeds occurring when the 10th St. or the 14th St. off-ramps were closed.

When the North Freeway was considered in conjunction with either the Northeast or Northwest Freeways, the speeds were significantly lowest when the North Ave. off-ramp was closed and were significantly highest under normal operation.

The speed and delay studies which were made on the surface streets were analyzed in two groups. The east-west streets were analyzed together and the north-south streets were analyzed together.

The analysis of variance investigation indicated there were no significant differences in the over-all travel speeds or running speeds on the east-west streets. Similar results were indicated for the north-south streets.

SURFACE STREET VOLUMES

The volumes which were observed on the north-south streets and the east-west

TABLE 8

RANK ORDER OF TOTAL OVER-ALL TRAVEL TIME AND SIGNIFICANT DIFFERENCES OF RAMP CONDITIONS[1]

Location	Rank Order of Total Over-all Travel With Ramp Closed at			
	Lowest	2nd Lowest	2nd Highest	Highest
North-South St.	Normal	North Ave.	10th St.	14th St.
East-West St.	Normal	14th St.	North Ave.	10th St.
North Freeway	10th St.	Normal	14th St.	North Ave.
Northeast Freeway	10th St.	Normal	North Ave.	14th St.
Northwest Freeway	14th St.	Normal	North Ave.	10th St.
Freeway and Sts.	Normal	14th St.	10th St.	North Ave.

[1] No significant differences in factors underlined together.

TABLE 9

TOTAL OVER-ALL TRAVEL TIME

Facility	Total Over-all Travel Time (veh-min)			
	Normal Operation	14th St. Ramp Closed	10th St. Ramp Closed	North Ave. Ramp Closed
Streets	34,836	39,408	41,117	37,275
Freeways and ramps	30,711	33,277	32,767	47,663
Total	65,547	72,685	73,884	84,938

streets were analyzed in a similar manner as were the speed and delay studies. The volumes which occurred between 7:00 and 8:00 AM were analyzed separately from the volumes which occurred between 8:00 and 9:00 AM.

The surface street volumes tended to be lowest when the Freeway was operating under normal conditions. But, the analysis of variance investigation indicated no significant differences among the ramp conditions for any of the groups of surface street volumes analyzed.

TOTAL OVER-ALL TRAVEL TIME

There were no significant differences in the total over-all travel time on the east-west streets under any of the ramp conditions. There were also no significant differences noted in total over-all travel time on the north-south streets under any of the ramp conditions.

The over-all travel time on the North Freeway was significantly highest when the North Ave. off-ramp was closed. There were no significant differences among the other ramp conditions for over-all travel time on the North Freeway.

The over-all travel times on the Northeast Freeway and the Northwest Freeway were not significantly different for any of the ramp conditions.

The total over-all travel time in the entire system of freeways and surface streets considered together was significantly highest when the North Ave. off-ramp was closed. There were no significant differences noted under any of the other ramp conditions. The travel times tended to be lowest under normal operation of the Freeway, though not significantly so.

Table 8 gives the rank order of total over-all travel times and significant differences of ramp conditions, and Table 9 gives a summary of the observed total over-all travel times.

TOTAL TRAVEL

The total travel on the freeways and streets expressed in vehicle-miles was analyzed

TABLE 10

RANK ORDER OF TOTAL OVER-ALL TRAVEL AND SIGNIFICANT DIFFERENCES OF RAMP CONDITIONS[1]

Location	Rank Order of Total Over-all Travel With Ramp Closed at			
	Lowest	2nd Lowest	2nd Highest	Highest
North-south	Normal	North Ave.	10th St.	14th St.
East-west	North Ave.	Normal	14th St.	10th St.
North Freeway	14th St.	North Ave.	10th St.	Normal
Northwest Freeway	14th St.	10th St.	Normal	North Ave.
Northeast Freeway	10th St.	14th St.	North Ave.	Normal
Freeway and Sts.	14th St.	Normal	North Ave.	10th St.

[1]No significant differences in factors underlined together.

TABLE 11

TOTAL OVER-ALL TRAVEL

Facility	Normal Operation	14th St. Ramp Closed	10th St. Ramp Closed	North Ave. Ramp Closed
Streets	9,821	10,731	10,560	10,316
Freeways and ramps	15,285	14,190	14,761	14,812
Total	25,106	24,921	25,321	25,128

in the same manner as were the speed and delay studies and the total over-all travel time.

The travel on the north-south streets was found to be significantly lowest when the Freeway was operating normally. Travel on the north-south streets was significantly higher when a ramp was closed on the Freeway, and one ramp closure was not significantly different from another.

Travel on the east-west streets was not significantly different under any ramp condition.

Travel on the North Freeway was significantly highest when the Freeway was operating normally. The closing of any one ramp was not significantly different from the closing of any other ramp. The results obtained for the Northwest Freeway were similar to that of the North Freeway.

Travel on the Northeast Freeway was not significantly different under any ramp condition.

Table 10 gives the rank order of total over-all travel and significant differences of ramp conditions, and Table 11 gives a summary of the observed total over-all travel time.

Closing any off-ramp significantly increased the travel on the north-south streets while significantly decreasing the travel on the North and Northwest Freeways. Furthermore, the closing of an off-ramp had no significant effect on the travel on the east-west streets, Northwest Freeway, or the system as a whole. Apparently the decrease in travel on some streets balanced the increase on the other streets causing no significant differences in the vehicle-miles traveled in the entire study area.

SUMMARY OF RESULTS

A summary of the results of the analysis of the data collected in this study can be outlined as follows:

1. Averaged over-all positions, the highest volumes occurred on the North Freeway when the Freeway was operating normally, and these volumes were significantly dif-

ferent from those observed when any of the ramps were closed. The volumes obtained when any of the off-ramps were closed were not significantly different from each other.

2. The traffic volumes decreased as one moved southward along the North Freeway from 14th St. to North Ave. The volumes observed at 10th St. and 5th St. were not significantly different from each other.

3. The speed on the North Freeway increased significantly between 14th St. and 10th St., when considering all ramp conditions, but there were not any significant differences in the speeds observed at the other study positions.

4. Averaged over-all positions, speeds were significantly lowest when the 14th St. off-ramp was closed. The highest speeds occurred when the 10th St. off-ramp was closed and under normal operation, and were not significantly different from each other.

5. When averaged over-all of the ramp conditions, density was significantly highest at 14th St. The densities observed at each of the other study positions were not significantly different from each other.

6. The significantly highest densities occurred at all study positions when the 14th St. off-ramp was closed.

7. Closing any one of the off-ramps did not significantly affect the density on the North Freeway at a study location prior to ramp that was closed.

8. Closing any one of the off-ramps on the Freeway tended to reduce the volume on the Freeway, and closing the 14th St. off-ramp or the North Ave. off-ramp tended to decrease the speeds and thus increase the densities as well.

9. The total over-all travel time on the Freeway was significantly greatest when the North Ave. off-ramp was closed. The travel time which occurred under the other conditions were not significantly different.

10. The total over-all travel time for the Freeway and streets was significantly highest when the North Ave. off-ramp was closed. The total travel time for other ramp conditions was not significantly different from each other.

11. The total travel on the Freeway was lowest when the 14th St. off-ramp was closed, and was highest when the Freeway was operating normally.

12. The total travel on the Freeway and streets was not significantly different for any ramp condition.

CONCLUSIONS

The following conclusions were determined after an evaluation of the results of analysis of data:

1. Studying the volume, speed, and density on a freeway at several different locations simultaneously with variable ramp spacings will give a more reliable indication of the actual traffic flow characteristics which exist on the freeway than will a point study.

2. Closing any one of the southbound off-ramps during the morning peak hour caused little or no improvement in the operating characteristics of the North Freeway. When a significant change was noted, it was usually a reduction in the quality of traffic flow.

3. Of all the ramp closings, the closing of the 10th St. southbound off-ramp caused the least change in the operating characteristics of the North Freeway.

4. The total over-all vehicle-minutes of travel time used by all the vehicles traveling through the freeway system is an effective measure of the level of service existing in a freeway system.

5. The relatively high density which was observed at North Ave. when the North Ave. southbound off-ramp was closed was apparently caused by the close proximity of the next exit, Williams St.

RECOMMENDATIONS

The following recommendations were made as a result of this study:

1. All off-ramps in the study area should remain open during the morning peak hour to provide optimum operation of the freeway and city streets.

2. For a freeway to efficiently handle the morning peak hour traffic flow into the central city, the off-ramps should be spaced as close together as possible, consistent

with the factors of design of the freeway and the ability of the surface street system in the vicinity of the off-ramp to accommodate the traffic from the ramp.

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