HIGHWAY RESEARCH RECORD

Number 21

Freeway Operations

7 Reports

Presented at the
42nd ANNUAL MEETING
January 7-11, 1963

HIGHWAY RESEARCH BOARD
of the
Division of Engineering and Industrial Research
National Academy of Sciences—
National Research Council
Washington, D. C.
1963

Department of Traffic and Operations

Fred W. Hurd, Chairman
Director, Bureau of Highway Traffic, Yale University
New Haven, Connecticut

COMMITTEE ON FREEWAY OPERATIONS

Alger F. Malo, Chairman
Director, Department of Streets and Traffic
Detroit, Michigan

Adolf D. May, Jr., Secretary
Illinois Expressway Surveillance Project, Oak Park

Louis E. Bender, Chief, Traffic Engineering Division, The Port of New York Authority, New York, N. Y.
Donald S. Berry, Chairman, Department of Civil Engineering, The Technological Institute, Northwestern University, Evanston, Illinois
Harold Cooper, Director, Traffic Division, Michigan State Highway Department, Lansing
Donald O. Covault, Associate Professor, Department of Civil Engineering, Georgia Institute of Technology, Atlanta
Charles J. Keese, Professor of Civil Engineering, Texas Transportation Institute, Texas A & M College, College Station
E. E. Lewarch, Traffic Engineer, Seattle, Washington
Eugene Maier, Director of Public Works, Houston, Texas
Burton W. Marsh, Director, Traffic Engineering and Safety Department, American Automobile Association, Washington, D. C.
William J. Miller, Jr., Director of Operations, Delaware State Highway Department, Dover
Theodore F. Morf, Assistant Chief State Highway Engineer, Illinois Division of Highways, Springfield
O. K. Normann, Deputy Director for Research, Office of Research and Development, U. S. Bureau of Public Roads, Washington, D. C.
Edmund R. Ricker, Director, Traffic Engineering Bureau, Pennsylvania Department of Highways, Harrisburg
Carlton C. Robinson, Director, Traffic Engineering Division, Automotive Safety Foundation, Washington, D. C.
Harold W. Sullivan, City of Los Angeles Police Department, Los Angeles, California
John L. Vardon, Route Analysis Engineer, Traffic Section, Ontario Department of Highways, Toronto, Canada
George M. Webb, Sacramento, California
Edward G. Wetzel, Tri-State Transportation Committee, New York, N. Y.

COMMITTEE ON CHARACTERISTICS OF TRAFFIC FLOW

Harold L. Michael, Chairman
Associate Director, Joint Highway Research Project, Purdue University
Lafayette, Indiana

Joseph C. Oppenlander, Secretary
School of Civil Engineering, Purdue University
Lafayette, Indiana

John E. Baerwald, Professor of Traffic Engineering, University of Illinois, Urbana
J. Stannard Baker, Director of Research and Development, The Traffic Institute, Northwestern University, Evanston, Illinois
C. E. Billion, San Diego, California
Paul D. Cribbins, Assistant Professor of Civil Engineering, North Carolina State College, Raleigh
J. E. P. Darrell, Traffic Engineer, Minnesota Department of Highways, St. Paul
H. M. Edwards, Associate Professor of Civil Engineering, Queen's University, Kingston, Ontario, Canada
Roy C. Haeusler, Automotive Safety Engineer, Engineering Division, Chrysler Corporation, Detroit, Michigan
J. E. Johnston, Deputy Director for Planning, Utah State Department of Highways, Salt Lake City
James H. Kell, Assistant Research Engineer, Institute of Transportation and Traffic Engineering, University of California, Berkeley
Warren L. Kessler, Assistant Traffic Engineer, Illinois Division of Highways, Springfield
W. A. McConnell, Executive Engineer, Technical Analysis, Engineering and Research Staff, Ford Motor Company, Dearborn, Michigan
Philip S. Mancini, Chief, Division of Traffic Engineering and Highway Planning, Rhode Island Department of Public Works, Providence
Robert L. Meyer, Traffic Engineer, Nebraska Department of Roads, Lincoln
O. J. Reichelderfer, Traffic Engineer, Pennsylvania Department of Highways Harrisburg
Neilon J. Rowan, Assistant Research Engineer, Texas Transportation Institute, Texas A & M College, College Station
Curtis L. Shufflebarger, Division of Traffic Operations, U. S. Bureau of Public Roads, Washington, D. C.
Robert P. Shumate, Director, Public Services Group, Indiana University, Bloomington
David Solomon, Chief, Traffic Control Branch, U. S. Bureau of Public Roads, Washington, D. C.
K. A. Stonex, Automotive Safety Engineer, Technical Liaison Section, Engineering Staff, General Motors Corporation, GM Technical Center, Warren, Michigan

Contents

A Study of Left-Hand Exit Ramps on Freeways

DONALD S. BERRY, GRAHAM L. D. ROSS, and RONALD C. PFEFER, respectively, Chairman, Department of Civil Engineering, and Research Assistants, Northwestern University

This paper reviews pertinent literature on operational aspects of left-hand ramps and gives a summary of the status of knowledge, along with a list of the more important references.

Time-lapse photography was used in making field studies of three left-hand exit ramps and one right-hand exit ramp on the Congress Street Expressway in Chicago. Detailed analyses of volume, speeds, density, exiting paths, and hazardous maneuvers were carried out and the results used to check a hypothetical formulation of the operational characteristics to be expected for left-hand exit ramps.

Special analyses were made of operational characteristics of "familiar" vs "unfamiliar" drivers, as determined by interviewing drivers after they had exited from the freeway. It was concluded that the left-hand exit ramps studied operate quite satisfactorily.

• PREVIOUSLY, most freeway ramps have been constructed on the right of the through traffic lanes, adjacent to the slowest-moving freeway lane. Observation, experience, and research have built up sufficient knowledge about traffic behavior in the vicinity of these right-hand ramps so that the engineer is able to state with a fair amount of certainty what is desirable in such cases.

Occasions arise, however, when it is expedient, desirable or even essential that the ramps be placed on the left of the through lanes. Observations have indicated that difficulties have occurred at left-hand ramps in some locations. However, little factual information is available on the traffic and physical conditions associated with operational problems.

It was, therefore, the purpose of this study to examine the present status of knowledge about left-hand ramps, to study the operational behavior patterns of traffic at some high-volume left-hand exit ramps in Illinois, and to draw conclusions about the suitability of such ramps.

PRESENT PRACTICE AND STATUS OF KNOWLEDGE

An annotated bibliography, prepared to provide a background for this study, revealed that most of the previous studies of ramps had dealt with right-hand entrance ramps. Right-hand exit ramps were considered in only a few studies, and left-hand ramps, either on- or off-ramps, generally were mentioned only in passing.

Because published data about left-hand ramps were so limited, a questionnaire was sent to all State highway departments in July 1961, requesting information about the extent of use of left-hand ramps, experience in their design and operation, and present and anticipated future plans and policy with regard to them. A 98 percent response was obtained by March 1963.

Analysis of the replies received to the questionnaire showed that 33 States had left-

Paper sponsored by Committee on Freeway Operations.

hand ramps in operation and 10 others had some left-hand ramps planned or under construction. Only 8 States had no left-hand ramps, with none planned or under construction. It is possibly significant that only 6 percent of the total number of interchanges reported were located in these 8 States which reported no left-hand ramps.

It was found that 332 left-hand ramps were reported as in operation, 123 under construction, and 405 being planned. Urban and suburban locations together had 75 to 80 percent of those interchanges incorporating the left-hand ramp. An average of 7.01 left-hand ramps per 100 interchanges was reported. One State reporting 410 interchanges (Texas) had 19 left-hand ramps per 100 interchanges.

There appeared to be no significant tendency to use left-hand ramps for either on- or off-ramps only. Left-hand ramps were mainly incorporated in directional interchanges, with about one-half that number in modified diamonds, and the balance in semi-directional and three-legged interchanges.

The considerations reported by the States as reasons for adopting left-hand ramps are summarized as follows, the number in brackets indicating the number of States so replying:

1. To meet a demand for a high-volume directional movement (23).
2. Economic considerations, mainly structural and land costs (16).
3. Right-of-way limitations (29).
4. Topography and natural barriers such as a river or a lake requiring special geometric treatment (19).
5. The elimination of weaving; for example, where it was necessary to provide exit facilities immediately downstream of an entrance ramp terminal, weaving conflicts between entering and exiting traffic could be avoided by placing one ramp terminal on the left of the through lanes (6).
6. Lack of left-turn storage at diamond interchanges. With left-hand on-ramps, it is possible to use the center lane on the cross-street as storage for both left-turn movements onto the freeway, without any restriction on length of the storage lane.
7. Left-hand off-ramps can also provide higher capacity at the cross-street by arranging for left-turning movements which do not cross each other.
8. To provide access to service and rest areas located in a widened median, as is done on some toll roads.
9. As part of a sequence of right-hand off-ramps and left-hand on-ramps, to provide service to several cross-streets in the central area which are situated too close together to permit providing access to these streets from one side of the freeway only; for example, Northwest Expressway, west of Chicago's Loop.

In the design of left-hand ramps, a few States reported that special consideration is given to some factors, such as adequate attention to signing (Oregon suggested the additional use of pavement messages approaching a left-hand exit), sight distance, target value, and interchange spacing.

Some States suggested that acceleration and deceleration lanes should be longer for left-hand ramps. California, before discontinuing the construction of left-hand ramps, required a parallel lane 1,000 ft long ahead of the exit nose, and Georgia suggested the use of a 1,500-ft deceleration lane. Washington and Illinois reported that the length of acceleration lanes should be based on merging requirements rather than on speed-change criteria, whereas Arizona, the District of Columbia, and Georgia suggested the continuation of an additional through lane to accommodate traffic entering from a left-hand on-ramp. Forty-three States reported no specific design standards for left-hand ramps.

A general reluctance to use left-hand ramps was evident on the part of the majority of responding States. As of April 1959, California had decided to eliminate the further use of left-hand ramps. The main considerations involved in this decision were those of safety and the reported adverse effect on capacity of the freeway because of slower-moving traffic weaving across the through lanes to an exit on the left. Michigan reported that all entrances and exits shall be on the right except (a) at directional ramps serving business-route traffic into or from a major city, (b) at major expressway interchanges based on traffic volume needs, and (c) at the beginning or end of dual sections of major routes, where the ramp design speed is never below 50 mph.

Of the 33 States having left-hand ramps in operation, 6 States reported no available data on operational problems, and 9 indicated no discernible problems. The main problems mentioned by the remaining States can be summarized as follows:

1. Repeated and hazardous lane changing by trucks and other vehicles moving at speeds slower than freeway running speeds, especially where trucks must enter or leave on an ascending grade. This problem was reported from California and Michigan, the States with the highest percentage of State highway completed to full freeway standards. Significantly, California is one of the three States having the mandatory requirements that all heavier trucks shall keep to the right.[1] The State of Michigan does not have such a legal requirement, but the City of Detroit (which accounts for a considerable percentage of controlled-access highway mileage in the State), does have a similar requirement.

2. An increase in weaving at left-hand off- and on-ramps. This is especially prevalent where interchanges are spaced close together and where the left-hand ramp is "isolated." (A left-hand ramp is considered to be "isolated" when it is the only left-hand ramp on the section of freeway, or when it is the first left-hand ramp encountered after traversing a freeway section with only right-hand ramps.)

3. The left-hand lane, the traditional high-speed lane, is slowed down as a result of merging maneuvers.

4. Some driver confusion and hesitancy results from being confronted by a left-hand off-ramp, especially where signing is poor and the facility is one carrying a high percentage of out-of-state traffic.

5. Increased accidents and hazardous maneuvers at left-hand on- and off-ramps were reported by Michigan, New Jersey, California, and Oregon. The prevalent type of accident appeared to be exiting from the wrong lane, and rear-end collisions caused by vehicles slowing up before exiting. The Michigan study (4), conducted at seven locations, found that left-hand exits had almost five times as many accidents as right-hand exits and that they were twelve times as severe and that left-hand entrances accounted for four times as many accidents which were six times as severe. Generally speaking, the information on the accident studies was suprisingly meager. Forty-three States, of which 26 have left-hand ramps in operation, reported that no accident data had been assembled on left-hand ramps.

Overall, the questionnaire study revealed considerable interest in left-hand ramps, but specific data on the operational problems just outlined were scarce.

TRAFFIC BEHAVIOR PATTERNS AND PARAMETERS

An hypothetical study of expected behavior of traffic at left-hand off-ramps was made, to aid in identifying the freeway flow parameters that should be investigated (8). Based on this analysis and the study of the literature, the following parameters were selected as those likely to be the most sensitive and effective indexes for use in a composite suitability rating for left-hand exit ramps:

1. The distribution of freeway volume by lane and the composition of flow (that is, the percentage of trucks) on the section of freeway immediately upstream from the off-ramp.

2. The distribution of speeds by lane at this upstream location, and the difference between the speeds of vehicles exiting and of vehicles continuing through in the adjacent lane.

---

[1] Delaware and Vermont also require trucks to travel in the right-hand lanes. Section 525.3 of the California Vehicle Code reads: "When any vehicle included in Section 515 is being driven on any highway, it shall be driven in the right-hand lane for traffic or as close as practicable to the right edge or curb, except when overtaking and passing another vehicle proceeding in the same direction, or when preparing for a left turn at an intersection or into a private road or driveway." Section 515 includes, "(1) Any motor truck and trailer, (2) Any motor truck alone or truck tractor with semitrailer having a gross weight, of vehicle and load or of such vehicles and load of 25,000 pounds or more."

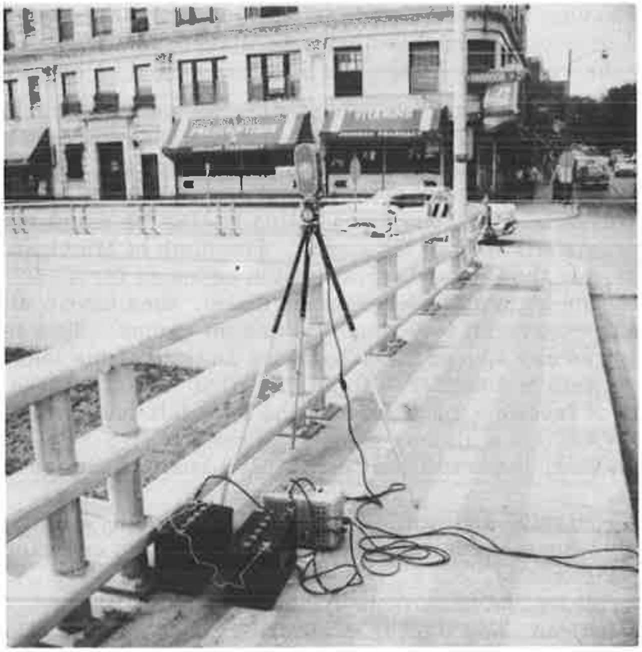


Figure 1. Time-lapse camera, with batteries and inverter set up on Oak Park Avenue overpass.

3. The point of exit onto the deceleration lane.
4. The frequency of occurrence of hazardous maneuvers and weaving in general.

The field studies were carried out by means of time-lapse photography, using 16-mm movie cameras driven by synchronous electric motors at either 60 or 100 frames per minute, powered either from a 110-v power supply or from a power pack consisting of a 12-v battery and an inverter (Fig. 1). The cameras were mounted in elevated positions, usually on suitable overpasses, but sometimes on a frontage road or clamped to utility poles. Generally, two and frequently three or more cameras were operated simultaneously. To provide a spatial base for analysis, whitewash lines were placed on the roadway shoulder at 50- or 100-ft intervals in the camera field of view. A check on the speed of the camera was obtained by placing a colored filter in front of the lens at specific intervals of time. Color film was used to facilitate identification of the same vehicles on films taken simultaneously at two separate locations.

The analysis of the films was carried out in the laboratory with the aid of commercial movie projectors, which back-projected the images onto ground glass screens (Fig. 2). A parallactic grid was constructed on this screen from the shoulder markings, thus giving a distance base. The projector had provision for advancing the film one frame at a time. A frame counter provided the time base.

Films were taken of operations at four ramps on the Congress Street Expressway, which runs west from the center of Chicago. The film studies were carried out at the Harlem westbound left-hand exit, the Harlem eastbound left-hand exit, and the Austin eastbound left-hand exit. For comparative purposes, studies were made of the First Avenue westbound right-hand exit. At the Harlem Avenue westbound left-hand exit, films were also taken of traffic for a distance of 3,300 feet back from the ramp itself.

Figures 3 and 4 show aerial views of Harlem and Austin interchanges, respectively. These interchanges are situated 8.6 and 7.5 mi west of Chicago's Loop and the expressway is depressed below ground level here. Figures 5 and 6 show the Harlem westbound left-hand exit ramp and the approaches to the exit. This ramp may be taken as typical

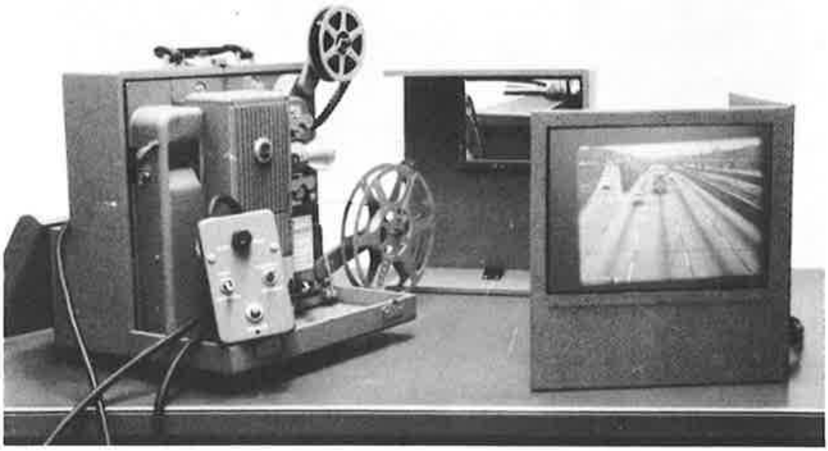


Figure 2. Kodak Analyst II projection apparatus.

of the left-hand exit ramps studied. On the approaches, the freeway lanes are 12 ft wide with distinctive lane markings on the concrete pavement.

Bituminous shoulders 10 ft wide are provided on both sides, and immediately ahead of the ramp the median is some 70 ft wide. The deceleration lane is paved in red concrete, is 450 ft long, and at the maximum point is 30 ft wide. The ramp proper, 900 ft long, has an upgrade of approximately 3 percent and terminates at a signalized intersection. The design provides an ample width for a single-lane take-off with provision for two lanes of traffic at the signalized intersection.

The First Avenue right-hand exit is located on the westbound section 10.4 mi west of Chicago's Loop. The approaching freeway lanes are level, with a well-designed high-speed exit which has an upgrade of approximately 0.5 percent.

To aid in the evaluation of the performance of the freeway at the left-hand exits, the flow characteristics were also compared with those for an "average" section of six-lane freeway. The flow characteristics for the "average" section had been developed by May (3), who summed up the results of six separate studies conducted in California, Michigan, New Jersey and Texas.

Volume Distribution by Lane

Because left-hand exit ramps undoubtedly have an effect on volume distribution by lane, this volume distribution was investigated for each of the four exit ramps, three left-hand and one right-hand, at points just ahead of the deceleration lanes. Also, in the case of the Harlem westbound exit ramp, volume distribution was investigated 1,900 ft and 3,300 ft upstream from the nose. These lane distribution results were then compared with those for the "average" section, for three levels of flow, as follows: "Low," corresponding to 25-54 vehicles per minute (vpm); "Med" to 54-85 vpm; "High" to a volume greater than 85 vpm.

Figure 7 shows the percentage of total volume carried in each lane on an "average" section of freeway for these three levels of flow. Figure 8a shows the percent volume carried in each lane at the beginning of the deceleration lane at the Harlem Avenue westbound left-hand exit ramp, also for the three levels of flow. This ramp had the highest volume of any of the left-hand ramps investigated, with 24-hr ramp volumes of 9,300 vehicles, and 800 vph from 4 to 5 PM. The three freeway lanes at a point just ahead of the ramp carried a 24-hr volume of 53,600 vehicles with 6,100 vph from 4 to 5 PM. The ramp was studied on two different occasions. The volume distributions found just ahead of the deceleration lane for each of the two separate studies agreed quite closely.

Figure 8a shows that, for the low range of traffic volumes, the percentage of vehicles in the left lane at the approach to the left-hand exit ramp was 5 percent higher than for

Figure 3. Aerial view, Congress-Harlem interchange.

Figure 4. Aerial view, Congress-Austin interchange.

the "average" distribution. As the total volume increased, the variation grew less. Particularly noticeable is the similarity between the volumes carried in the left and center lanes, at all total volumes.

At a point downstream, opposite the nose of the ramp terminal, at all levels of flow the traffic was distributed so that about 25 percent of the total volume was in the left lane, 25 percent in the right lane, and the remaining 50 percent in the center lane. Even with a total volume of 6,100 vph approaching the ramp terminal, and about 12 percent exiting, one-quarter of the through traffic chose to remain in the left lane, indicating that the presence of the left-hand off-ramp did not deter through traffic from using the left lane.

Figures 8b and 8c show the distribution of traffic 1,900 ft and 3,300 ft before the nose. At all three volume levels, the percent of vehicles using the left lane increased somewhat as traffic approached the left-hand off-ramp, as might be expected.

The volume distribution by lane found just upstream of the deceleration lane at the right-hand exit ramp at First Avenue, 1.8 mi west of Harlem interchange, is also

Figure 5. Freeway lanes and Harlem Avenue left-hand exit from Home Avenue pedestrian overpass looking west.

Figure 6. Freeway lanes approaching Harlem Avenue left-hand exit from Home Avenue pedestrian overpass looking east.

plotted for the three levels of flow (Fig. 9). At this right-hand exit, there was, generally speaking, a greater percent of traffic in the right lane than on the "average" freeway section, as would also be expected.

An interesting comparison apparent from these figures is that, at high total volumes, the volume distributions by lane upstream from both the left-hand and the right-hand exits were quite similar to that for May's average freeway section. At low volume levels, the left lane at the approach to the left-hand off-ramp carried an appreciably greater volume than at the approach to the right-hand ramp.

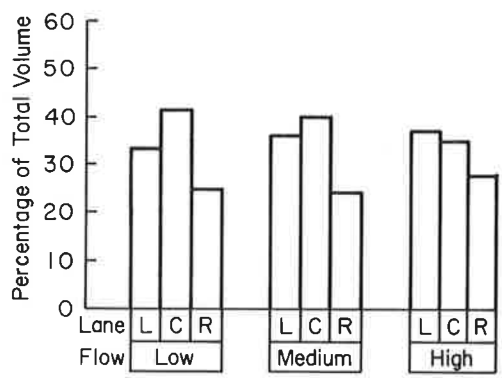


Figure 7. Volume distribution by lane for "average" section of freeway (3).

These studies of volume distribution by lane indicate that level freeways with left-hand exit ramps can carry high volumes. Even though the percentage of vehicles in the left lane was high, the pattern of volume distribution by lane showed no substantial changes as the ramp was approached. It appears that total volumes in the region of 6,000 vph can easily be handled on a level three-lane section of freeway adjacent to a left-hand exit, where 13 percent of the total flow exits, provided that the exiting maneuver be executed at high speed.

Speed

A left-hand exit ramp could have an adverse effect on speed in either of two ways: (a) so many vehicles would use the left-hand lane that sheer congestion would cause a lowering of the speed in that lane as compared with the speed in the other two lanes, and (b) slow-moving vehicles moving into the left-hand lane to exit could cause a reduction in the speed of other vehicles in the left lane. Investigations were, therefore, carried out on the various ramps studied to compare for left-hand and right-hand exit ramps, the speeds in the three lanes just upstream from the deceleration lane, and also to compare the speeds of the exiting vehicles with the speeds of through vehicles in the adjacent lane.

Figure 10a shows the average speed in each lane, for three volume groupings just upstream from the Harlem Avenue westbound left-hand exit ramp. Figures 10b, 10c, and 10d show similar information for one right-hand exit location (First Avenue westbound) and for two other locations with left-hand ramps (Austin Avenue eastbound and Harlem Avenue eastbound).

Investigation of the speed-volume relationships at these four exit ramps indicated that the left-hand exit ramps did not adversely affect the freeway flow. At low volumes, average speeds were above 50 mph for left lanes approaching all three left-hand exit ramps, and were higher than the average speed for the left lane at the right-hand exit at First Avenue. At medium volume levels at the three left-hand exits, average speeds for left lanes were also close to 50 mph. At high-volume levels, constrictions of flow downstream from the two left-hand exits and the right-hand exit reduced average speeds in all lanes.

Analysis was made of the speeds of vehicles exiting at each study location and the speeds of vehicles proceeding through in the lane adjacent to the deceleration lane at that location. Figures 11a and 11b show the relationships found for the Harlem Avenue westbound left-hand exit and First Avenue westbound right-hand exit. At low volume only, the average speeds of the exiting vehicles at both left- and right-hand ramps were noticeably lower than the average speeds of through vehicles.

As the total volume rose, the differential between the exiting and through speeds decreased in a similar manner for both left- and right-hand exit ramps. It was felt, therefore, that because the greater differential in exiting and through speeds occurred at lower volumes where the effect would be less noticeable and, because this difference was not apparent at higher levels of flow, the presence of the exiting vehicles in the left lane approaching the left-hand off-ramp apparently did not affect the speeds in that lane, for these locations on this level freeway.

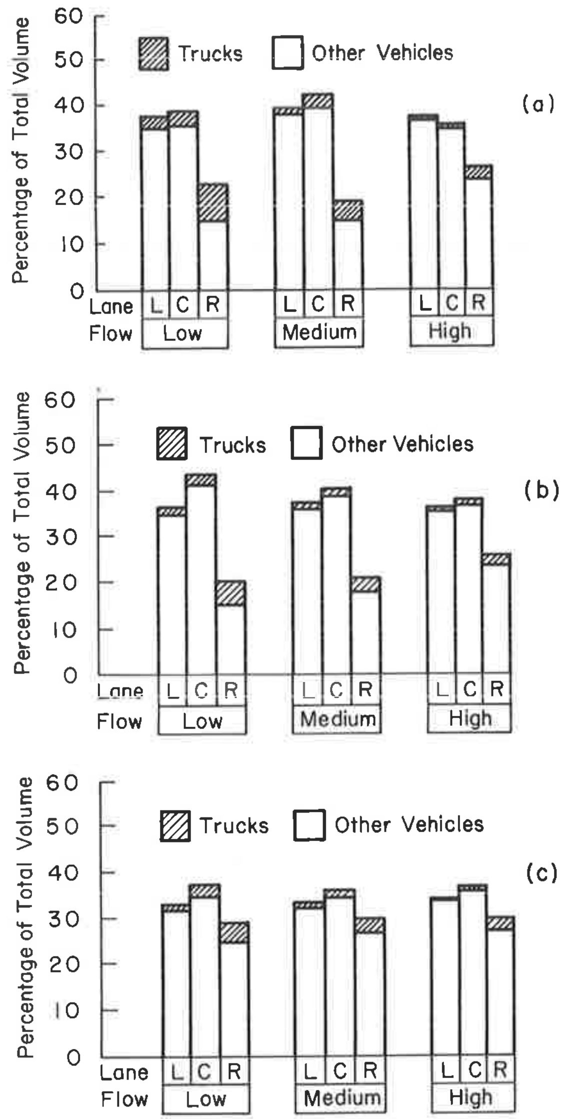


Figure 8. Volume distribution by lane approaching left-hand exit ramp, Harlem Avenue westbound, Thursday, June 29, 1961: (a) at beginning of deceleration lane; (b) 1,900 ft upstream from deceleration lane; (c) 3,000 ft upstream from deceleration lane.

It can be concluded that a left-hand exit ramp, with a high exiting design speed, generally does not have an adverse effect on the speed of operation of the traffic on a level freeway merely because it is situated on the left-hand side of the through pavement.

Volume Density

Studies were made of lane densities in a 300-ft section of freeway approaching each exit ramp. These densities were determined from the time-lapse films by counting the number of vehicles in each lane in the 300-ft sections. Samples were taken for every other frame for each of 503 15-sec periods for the same 2 hr of traffic that was studied for volumes and speeds (Figs. 7 through 10). Average 15-sec lane volumes were then computed for all 15-sec samples with the same lane-density grouping.

Table 1 gives the average 15-sec lane volumes, $\bar{v}$, as obtained for each lane-density grouping above 30 vehicles per mile for westbound freeway sections approaching the Harlem Avenue left-hand exit, and for the First Avenue right-hand exit. The number of 15-sec samples are given as n in the table.

There was considerable scatter in the 15-sec lane volumes for each 10-vpm density grouping, so it is not possible to state that the average lane volumes for different density groupings in Table 1 are significantly greater for the left-hand exit location, as compared with the First Avenue location.

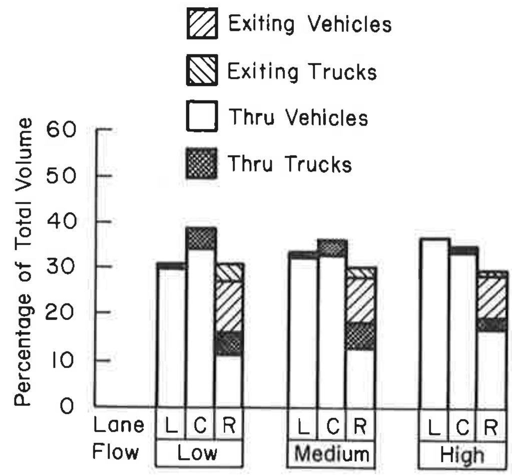


Figure 9. Volume distribution by lane at right-hand exit ramp, First Avenue westbound, Monday, March 5, 1962.

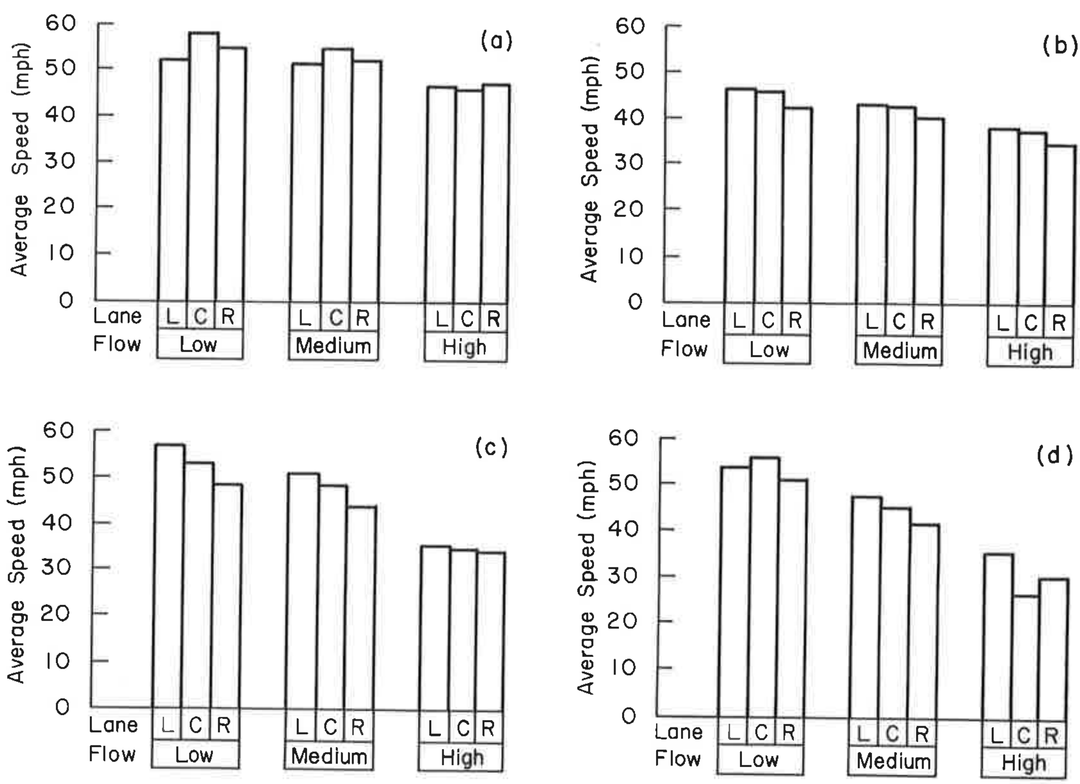


Figure 10. Mean speeds by lane at three volume levels at beginning of deceleration lanes on Congress Street Expressway: (a) left-hand exit, Harlem Avenue westbound, Tuesday, March 20, 1962; (b) right-hand exit, First Avenue westbound, Monday, March 19, 1962; (c) left-hand exit, Austin Avenue eastbound, Tuesday, March 20, 1962; (d) left-hand exit, Harlem Avenue eastbound, Thursday, March 22, 1962.

TABLE 1

AVERAGE 15-SEC LANE VOLUMES ($\bar{v}$), AT DIFFERENT LANE DENSITIES IN APPROACHES TO TWO EXIT RAMPS ON CONGRESS STREET EXPRESSWAY, SPRING 1962

Exit Ramp	Lane	30 to 49 Veh/Mi		40 to 49 Veh/Mi		50 to 59 Veh/Mi		60 to 69 Veh/Mi		70 to 79 Veh/Mi		80 to 120 Veh/Mi	
		n	$\bar{v}$	n	$\bar{v}$	n	$\bar{v}$	n	$\bar{v}$	n	$\bar{v}$	n	$\bar{v}$
Left-hand[1]	Left	28	5.9	28	8.5	13	9.5	3	9.9	1	10	--	--
	Center	30	7.8	23	9.3	16	9.7	2	10	3	10	--	--
	Right	18	6.6	13	7.7	2	8	1	9	--	--	--	--
Right-hand[2]	Left	26	5.2	26	5.8	10	7.6	19	8.2	13	8.2	3	10
	Center	27	6.1	26	7.6	16	8.7	25	8.8	13	9.5	3	10
	Right	18	5.3	21	6.8	20	8.0	22	8.6	18	9.4	16	10.4

[1] Harlem Avenue westbound.
[2] First Avenue westbound.

It was quite apparent, however, that for each density grouping, all lanes at the approach to the left-hand exit were carrying higher volumes (and at higher speeds) than the corresponding lanes at a point upstream from the right-hand exit.

Therefore, this density analysis did not reveal any data indicating that this left-hand exit ramp was not operating satisfactorily. In contrast, it indicates that the section in advance of the left-hand exit ramp was operating better than the section in advance of the right-hand exit ramp, for these particular periods of filming.

Density analyses were also made for each lane approaching the two left-hand exit ramps on the eastbound roadway of Congress Street Expressway. Because the density values were affected by the backup of queues caused by restrictions downstream from each ramp, the results are not presented here. The data presented for the two ramps in Table 1 are for conditions when there generally was no backup affecting the flow through the exit ramp terminals.

Truck Considerations

One of the major reasons for questioning the suitability of the left-hand ramp has been the possible problems resulting when trucks and other slower vehicles, which normally travel in the right-hand lane, attempt to enter or leave via a left-hand ramp. This problem therefore, was given special study.

As a first step, data were taken of the composition of flow by lane just upstream from the three left-hand exit ramps and the one right-hand exit ramp. The results obtained for left-hand exit ramps were compared with results for the First Avenue right-hand exit ramp (Figs. 8 and 9).

There is no mandatory requirement that trucks should keep to the right on Congress Street Expressway; there is only a sign stating "Slower Traffic Keep Right." However, it is apparent that the greater percentage of trucks do travel in the right-hand lane, at both right-hand and left-hand exit locations. It was found that the left lane carried a larger percentage of trucks on the approach to a left-hand than on the approach to a right-hand ramp, due to the need for some trucks to get into the left lane to exit.

The movements of trucks in the left-hand lane of the Congress Street Expressway were also traced over a filming period of 16 min at the Harlem westbound off-ramp for a distance of 3,300 ft ahead of the exit, utilizing several cameras operating simultaneously. It was found that 80 percent of the exiting trucks were already in the left-hand lane 3,300 ft ahead of the ramp. The other 20 percent of the exiting trucks did not appear to have had difficulty in reaching the left-hand lane, on this level section of freeway.

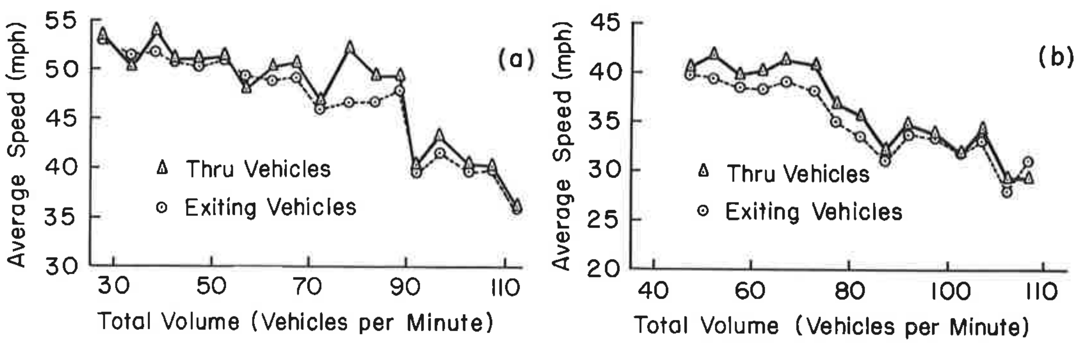


Figure 11. Speeds of exiting and through vehicles upstream from ramp, in lane adjacent to ramp, Congress Street Expressway: (a) Harlem Avenue westbound, left-hand exit, Tuesday, March 20, 1962; (b) First Avenue westbound, right-hand exit, Monday, March 19, 1962.

Although this study was made on a level freeway, it can be expected that adverse grades would have had an effect on truck speeds. Previous investigation (5) has revealed that grades as low as 1.7 percent may affect operations somewhat even when truck volumes are as low as 2 or 3 percent. A recent analysis (1) shows, however, that sustained grades up to 2.7 percent do not cause trucks with a weight-power ratio lower than 200 to decrease speed below an initial 50 mph, and it is only when the weight-power ratio is 300 or 400 that the decrease in speed is considerable. This would appear to indicate that further studies of the operational effects of different types of trucks would be warranted at locations with ascending grades.

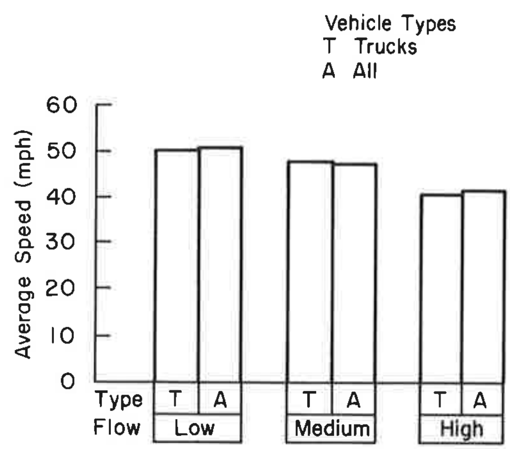


Figure 12. Speeds of exiting trucks vs all exiting vehicles, Harlem Avenue westbound, left-hand exit, Tuesday, March 20, 1962.

A comparison was made of the average exiting speeds of trucks and the average exiting speeds of all vehicles at the Harlem Avenue westbound left-hand exit ramp. Figure 12 shows the results. At low and high flows, the average truck speed was only 0.8 mph less than the average speed of all exiting vehicles, whereas at intermediate flows, the speed of exiting trucks actually averaged 0.3 mph higher than that of all exiting vehicles.

It was concluded that the operation of the left-hand exit ramps studied was not adversely affected by the percentage of trucks normally using the freeway or the ramps, at this level section of freeway.

Departure Zones

The point at which vehicles start to leave the through roadway at an exit ramp is an indication of how well the ramp is operating, assuming that the design of the ramp proper is such that no advantage is gained by making a late exit. To this end, a study was made of all the ramps investigated. A vehicle was recorded as departing from the freeway lanes when one wheel was wholly on the auxiliary pavement.

The investigation showed the exit pattern to be very consistent, with over 90 percent of all vehicles exiting within 100 ft of the beginning of the auxiliary pavement in all cases. The volume did not appear greatly to affect the point of departure, although some tendency was noticed for vehicles to make a slightly earlier departure when total volume increased. All the ramps studied had high exit design speeds and flat angles of departure.

Hazardous Maneuvers

Hazardous maneuvers resulting from inattention or faulty judgment of unskilled drivers can occur at either right-hand or left-hand exit ramps. However, a higher frequency of hazardous maneuvers might be expected at left-hand than at right-hand exits because of the following:

1. Drivers planning to leave a freeway may expect the exit to be on the right and thus more of them may be in the wrong lane when approaching a left-hand exit than when approaching a right-hand exit.
2. Slower-moving vehicles, including trucks, may impede the faster vehicles in the left lanes as they force their way across to a left-hand exit ramp.
3. Left-hand exit ramps may be poorly designed (inadequate target value, too short a deceleration section, or inadequate signing), which may have more serious effects because of higher speeds in left-hand lanes.

Studies were made of the frequency of hazardous maneuvers at each of several exit ramps (three left-hand and one right-hand exit ramps). Tables 2 and 3 give results for 120 min of observation.

The most prevalent type of hazardous maneuver was the exit from the center lane. However, the incidence of all hazardous maneuvers was so low that it was not possible to draw any definite conclusions. The incidence was about equal for both left-hand and right-hand exits. Studies of accident experience will be desirable, as more time elapses, to permit a more definitive comparison.

THE UNFAMILIAR DRIVER

In evaluating the suitability of left-hand exit ramps, studies also were made of the hypothesis that a left-hand exit ramp might have more of an adverse effect on the "unfamiliar" driver than on the driver who had previously used that left-hand ramp. It was considered probable that the unfamiliar driver would be more likely to be adversely affected by the left-hand exit ramp. These adverse effects would be reflected in lane use in approaching the ramp, and in speeds and frequency of hazardous maneuvers.

Accordingly, a study procedure was developed to permit identifying the unfamiliar driver and to examine his driving behavior as he approached the left-hand exit ramps.

The classification of drivers was accomplished at the study sites by interviewing the exiting drivers who were stopped by the traffic signal at the top of the ramp. A driver reporting that he had used the ramp before the interview was classified as a "familiar" driver, and those who had not used the ramp before were classified as "unfamiliar."

A separate questionnaire was prepared for each of the two classifications of drivers and the appropriate questionnaire (each of which was identified by a serial number) was handed to each driver interviewed. The interviewer recorded the signal cycle number (referenced from the beginning of filming), the driver's position in the queue at the light, and the questionnaire number. This method allowed the identification on the film of the vehicle of each individual driver interviewed.

Each questionnaire included questions about the type of driver, the familiarity of the driver with the ramp and the expressway, the driver's opinions about the left-hand ramp, and related items.

The film analysis of the performance of the unfamiliar and familiar driver showed that, for low levels of flow, the average exiting speed of the unfamiliar driver was significantly lower than the average exiting speeds of the familiar driver and the through vehicles as well (6). This was not the case at higher levels of flow.

Generally, the point of departure characteristics of the familiar and the unfamiliar

TABLE 2

HAZARDOUS MANEUVERS AT FOUR RAMP TERMINALS ON CONGRESS STREET EXPRESSWAY, TWO HOURS OF OBSERVATIONS, SPRING 1962

Type of Hazardous Maneuver	Number of Maneuvers[1]											
	At Left-Hand Exit, Harlem, Westbound			At Right-Hand Exit, First Westbound			At Left-Hand Exit, Harlem, Eastbound			At Left-Hand Exit, Austin, Eastbound		
	Low Vol.	Med. Vol.	High Vol.	Low Vol.	Med. Vol.	High Vol.	Low Vol.	Med. Vol.	High Vol.	Low Vol.	Med. Vol.	High Vol.
Exit from center lane	2	8	8(1)	5(1)	11	4	14(3)	11(1)	0	0	0	0
Exit from far lane	1	0	0	0	3	0	3(1)	1	0	0	0	0
Off and on	0	4	1	0	3(1)	0	1	0	0	1	0	0
Cutting in	0	0	1	0	0	0	0	1	0	0	0	0
Late exit	3	3(1)	2	0	6	2	0	4	0	2	2	0
Total	6	15	12	5	23	6	18	17	0	3	2	0

[1] Numbers in parentheses refer to hazardous maneuvers executed by trucks.

driver differed little. It was found that at low traffic-volumes a significantly greater number of unfamiliar drivers departed at a distance greater than 100 ft than did familiar drivers.

Of all questionnaires distributed, 58.9 percent were returned. An analysis of these questionnaires revealed the following.

Familiar Drivers

Only a minute percentage of the familiar drivers answering stated that they had not intended to exit at the particular ramp at which they were interviewed. Several of the drivers had planned to exit at the previous right-hand exit, but had been trapped in left lane.

Approximately 80 percent of the familiar drivers remembered that their exit was on the left side of the traveled way. However, slightly more than one-half the familiar drivers stated that they were aware of their proximity to their regular exit by the use of signs. About one-third recognized it by the use of landmarks and similar orienting devices.

Individual opinions about the suitability of left-hand ramps were reported by many of the familiar drivers. The majority reported that a combination of both left- and right-hand exits was "okay"; about one-third felt that left-hand exits should be eliminated in future designs. A large number of familiar drivers expressed the feeling that it did not matter so much on which side of the expressway the exit was placed, so long as the placing was consistent.

Unfamiliar Drivers

Inspection of the returns from the unfamiliar driver showed that about 15 percent had not wanted to exit at the particular ramp at which they were interviewed. Several had missed the previous left-hand exit; others chose to leave because of congestion on the expressway ahead. Some had been trapped in the left lane, but desired to exit at the previous right-hand exit as had been the case for some of the familiar drivers.

More than 70 percent of the unfamiliar drivers first knew that the exit was on the left because of a sign; another 14 percent identified the exit because they actually saw

TABLE 3

HAZARDOUS MANEUVERS EXPRESSED AS PERCENT OF VOLUMES ON THE EXPRESSWAY

Flow Included in Volume	At Left-Hand Exit, Harlem, Westbound		At Right-Hand Exit, First, Westbound		At Left-Hand Exit, Harlem, Eastbound		At Left-Hand Exit, Austin, Eastbound	
	Volume	Percent	Volume	Percent	Volume	Percent	Volume	Percent
Exiting vehicles	1,454	2.27	1,129	3.02	725	4.83	425	1.18
Exiting veh. plus those in adj. lane	4,838	0.68	4,595	0.74	3,101	1.13	2,869	0.17
Exiting veh. plus those in all through lanes	9,856	0.33	9,868	0.34	7,798	0.45	7,728	0.06

the ramp. Of those remembering a sign which was of particular help to them, the greatest proportion of unfamiliar drivers stated that the sign one mile ahead of the ramp was the most help.

A majority of unfamiliar drivers felt that a combination of both left-hand and right-hand exits was "okay," whereas one-third of them suggested that left-hand exits should be eliminated in the future. Here again, as for the familiar driver, several unfamiliar drivers stated that consistency in the placement of exits was the primary factor rather than whether their position was on the left- or right-hand side.

Almost one-half the familiar drivers suggested the need for improvements on the signing approaching a left-hand ramp. A large proportion of unfamiliar drivers stated that more advance warning was needed to improve the efficiency of the left-hand ramps. A slightly smaller proportion felt that nothing need be done.

From this analysis, it appears that the majority of both familiar and unfamiliar drivers rely on adequate directional signing to aid them in using left-hand exit ramps. In general, the drivers were not opposed to a combination of left-hand and right-hand exits.

APPLICABILITY OF RESULTS TO OTHER AREAS

To appraise the applicability of the results of the Congress Street Expressway study to left-hand exit ramps on other freeways where driver characteristics might be expected to differ, a direct evaluation technique was developed. This technique involved manual sampling of volume distribution by lane and samplings of speeds by lane, exit paths, and hazardous maneuvers. The direct evaluation technique was checked against results obtained by time-lapse photography in a controlled test and was found to yield appraisals of suitability that were comparable to those via the use of photography (7).

The direct evaluation technique was used to study a total of five left-hand and four right-hand exit ramps. Two of the left-hand ramps were situated in California; the Fifth Street southbound exit from US 66 in San Bernardino, and the Cabrillo Boulevard northbound exit from US 101, south of Santa Barbara.

The exiting maneuvers at all sites conformed to a pattern consistent with the findings of the Congress Street Expressway study, as modified to allow for the effects of the differences in the physical layout of each site.

Although more investigation is desirable, it appears probable that the findings of the Congress Street Expressway studies are applicable in other parts of the country as well.

CONCLUSIONS

The conclusions stated here are based mainly on results of a study of three left-hand exit ramps and one right-hand exit ramp, located on a six-lane section of the Congress Street Expressway in Chicago, Ill. Although the studies were quite detailed, the scope of ramp and freeway configuration was limited due to the similarity of location and design of the three left-hand exit ramps. The three left-hand exit ramps are elements of two successive diamond interchanges which are the only interchanges along the entire section of the freeway having left-hand ramps. Each ramp studied had a direct, high-type design which permitted high exit speeds. Adequate directional signing was provided in advance of each left-hand exit. During the study, the freeway roadway carried up to 6,100 vph in one direction, with ramp volumes up to 800 vph, including 70 trucks.

For this type and location of left-hand exit ramp, the following can be concluded from this study:

1. The left lane, at an approach to this type of left-hand exit ramp, does not tend to carry an appreciably greater percentage of the total volume than at an approach to a right-hand ramp, except at low volume levels. At intermediate and particularly at high volumes, the through drivers at these left-hand exits apparently tend to compensate for the unbalancing effects of exiting vehicles in the left lane by using the other two lanes.
2. Such left-hand exit ramps generally do not have an adverse effect on the speed of operation of the traffic.
3. No noticeable increases in density, or bunching of vehicles, are found upstream from these left-hand exit ramps, resulting from exit ramp operation.
4. The operation of these left-hand exit ramps is not adversely affected by the percentage of trucks normally using this level freeway or its ramps, under regulations which do not require trucks to keep right.
5. The majority of vehicles begin exiting in the first hundred feet of the deceleration lane.
6. There was no indication from these studies that hazardous maneuvers are more prevalent at this type of left-hand exit than at right-hand exits designed for high-speed exiting.
7. Adequate advance directional signing is relied on to a great extent by the "unfamiliar" drivers to advise them that their exit ramp is on the left-hand side. The "familiar" driver generally remembers when this exit is on the left, but depends largely on directional signing for notification of approach to the particular exit.

RECOMMENDATIONS FOR FURTHER STUDIES

1. Further study is needed to determine the suitability of left-hand ramps under a wider range of conditions, as follows:
   a. Further studies are desirable to determine to what extent these conclusions apply to left-hand exit ramps located on upgrade freeway sections, provided that such sites can be found.
   b. Additional studies of left-hand exit ramps will be desirable to investigate other variables as follows:
      (1) Variations in geometric design other than grade of freeway.
      (2) Variations in traffic volume and composition.
      (3) Variations in the type of interchange which uses the left-hand exit ramps, and variations in the sequencing and location of left-hand and right-hand exit and entrance ramps.
2. In the previous study, the great majority of the exiting vehicles were already in the left-hand lane 3,300 ft ahead of the left-hand exit. Additional studies of the lane-changing practices of exiting vehicles should be made for even greater distances upstream of the exit.
3. As accident data become available, studies should be made of comparative hazard of left-hand ramps under different physical and traffic conditions.
4. The present study of left-hand ramps should be extended to encompass entrance ramps.

ACKNOWLEDGMENT

This research project was conducted by the Civil Engineering Department of Northwestern University under the sponsorship of the Illinois Division of Highways, in cooperation with the U. S. Department of Commerce, Bureau of Public Roads. Acknowledgment is made to members of these organizations who served on the Project Advisory Committee, for their valuable advice and assistance. Thanks are also due to staff members of the Chicago (District Ten) Office, Illinois Division of Highways, the Congress Expressway Surveillance Project, and the Chicago Area Transportation Study who assisted in various aspects of the project.

Gratitude is expressed to Richard D. Worrall and Carel J. Grove who, as Graduate Research Assistants in Civil Engineering at Northwestern University, made significant contributions to data gathering and analysis, and to Jack Leisch, Chief Highway Engineer of DeLeuw Cather Company, and A. A. Carter, Division of Traffic Operations, Office of Research, Bureau of Public Roads, for their advice.

REFERENCES

1. Firey, J. C. and Peterson, E. W., "An Analysis of Speed Changes for Large Transport Trucks." HRB Bull. 334, 1-26 (1962).
2. Grove, C. J., "The Suitability of Left-Hand Ramps for Freeways with Detailed Consideration of the Exit Ramp." M. S. thesis, Northwestern University (1961).
3. May, A. D., Jr., "Traffic Characteristics and Phenomena on High Density Controlled Access Facilities." Traffic Engineering (March 1961).
4. "A Comparison of Left-Hand Entrances and Exits with Right-Hand Entrances and Exits on a Divided Limited Access Highway." Michigan State Highway Department, Traffic Division (June 1958).
5. Moskowitz, K., "Research on Operating Characteristics of Freeways." Proc., Inst. of Traffic Engineers (1956).
6. Pfefer, R. C., "The Left-Hand Ramp and the Unfamiliar Driver." M. S. thesis, Northwestern University (1962).
7. Ross, G. L. D., "Direct Evaluation of Left-Hand Ramp Operation." M.S. thesis, Northwestern University (1962).
8. Worrall, R. D., "An Analysis of the Operational Characteristics of a Left-Hand Off-Ramp on a High Density Urban Freeway." M. S. thesis, Northwestern University (1961).

Traffic Behavior and Off-Ramp Design

ICHIRO FUKUTOME and KARL MOSKOWITZ, Assistant Traffic Engineers, California Division of Highways

• OFF-RAMP terminals on California Freeways are designed according to the direct angular take-off principle, as contrasted with the parallel deceleration lane principle. This design is a modification stemming from the off-ramp design of the added full lane preceded by a taper which was at one time standard. It was observed that almost no drivers actually drove the reverse curve alignment that this design called for, and this led to the statewide use of the direct type of off-ramps. Some of the reverse-curve types of off-ramps at major interchanges were reconstructed as directional-type ramps.

The shape of the direct type of off-ramp as it leaves the freeway is considered generally satisfactory, but the damage to guardrails and markers, the tire scuffs on curbs, and some reported accidents indicate that the deceleration distance to the ramp curve beyond the curb nose may be inadequate. This study was made to obtain factual data on the operating characteristics of the traffic as it leaves the freeway on various existing off-ramps. The objective was to determine whether the length of the ramp tangent approaching the ramp curve has any effect on ramp speed, and if it does, what the optimum length of such a tangent is.

METHODS

To obtain this objective, the speeds at various locations along the ramp were observed.

Off-Ramps Studied

For the purpose of this study 8 existing off-ramps were observed. Three were in the San Francisco Bay area (sites 11, 21 and 31), four in the Los Angeles area (sites 41, 51, 61, and 71), and one in Sacramento (site 81). Exit speeds were not posted at the ramps and the prima facie speed limit at the time of the study was 55 mph.

The description of these ramps follows:

Site 11.—Northbound off-ramp to First Avenue on the Eastshore Freeway in Oakland (Fig. 1). The ramp connects to a loop of a two-quadrant cloverleaf interchange. The reversing curve of the off-ramp appears to slow traffic on the ramp. The distance from the curb nose of the ramp to the B.C. of the 250-ft radius curve is 167 ft. It is an additional 121 ft to the PCC of the 150-ft radius curve. The off-ramp passes under the First Avenue overcrossing.

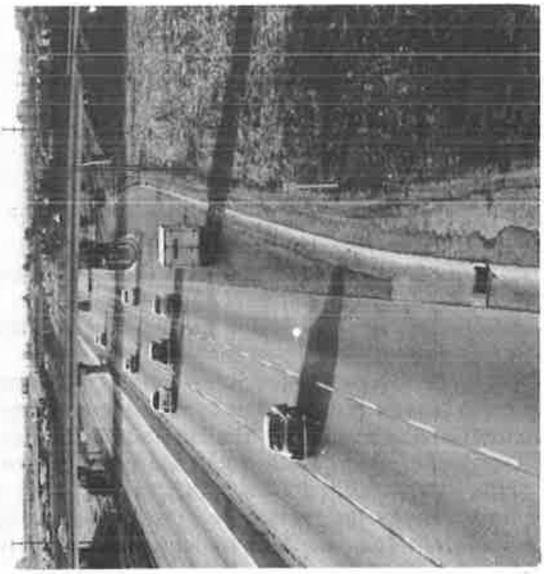
Site 21.—Southbound off-ramp to Winton Avenue on the Eastshore Freeway in Hayward (Fig. 2). The distance from the curb nose to the B.C. of the 400-ft radius curve is 490 ft.

Site 31.—Northbound off-ramp to Gilman Avenue on the Eastshore Freeway in Berkeley (Fig. 3). The ramp widens to two lanes 350 ft beyond the curb nose. The distance from curb nose to "Stop" sign at end of this diamond-type off-ramp is 990 ft.

Site 32.—Approach to "Stop" sign at end of diamond-type off-ramp to Gilman Street (Fig. 4).

Site 41.—Southbound off-ramp to Lakewood Boulevard on the Santa Ana Freeway (Fig. 5). The B.C. of the 250-ft radius curve is at the nose of the off-ramp. The free-

Paper sponsored by Committee on Freeway Operations.



way at this point is on a +2.30 percent grade. The crest of the vertical curve on the ramp is 110 ft beyond the nose.

Site 51.—Westbound off-ramp to Rosemead Boulevard on the San Bernardino Freeway. The interchange is a full cloverleaf-type design with a collector road for turning traffic (Fig. 6). The distance from the curb nose to the dividing point where the northbound on Rosemead enters a 200-ft radius curve to the right and the southbound on Rosemead travels straight ahead is 350 ft. Sight distance is no problem. The freeway is on a +0.96 percent grade. The off-ramp gore is striped as shown.

Site 61.—Westbound off-ramp to Temple City Boulevard on the San Bernardino Freeway (Fig. 7). The B.C. of the 130-ft radius curve is 100 ft beyond the curb nose of the ramp. The freeway is on a sag vertical curve with the grade at the beginning of the ramp approximately -1.4 percent. The off-ramp gore is striped.

Site 71.—Eastbound off-ramp to Vincent Avenue on the San Bernardino Freeway (Fig. 8). The freeway is on +0.94 percent grade. The distance from curb nose to B.C. of the 141-ft radius curve is 82 ft. The off-ramp gore is striped.

Site 81.—Northbound off-ramp to Arden Way on the Elvas Freeway in North Sacramento (Fig. 9). At this location the freeway is on a 2,000-ft radius curve and the off-ramp is also on a 2,000-ft radius curve. Sight distance is not a problem. The ramp merges with an off-ramp from the North

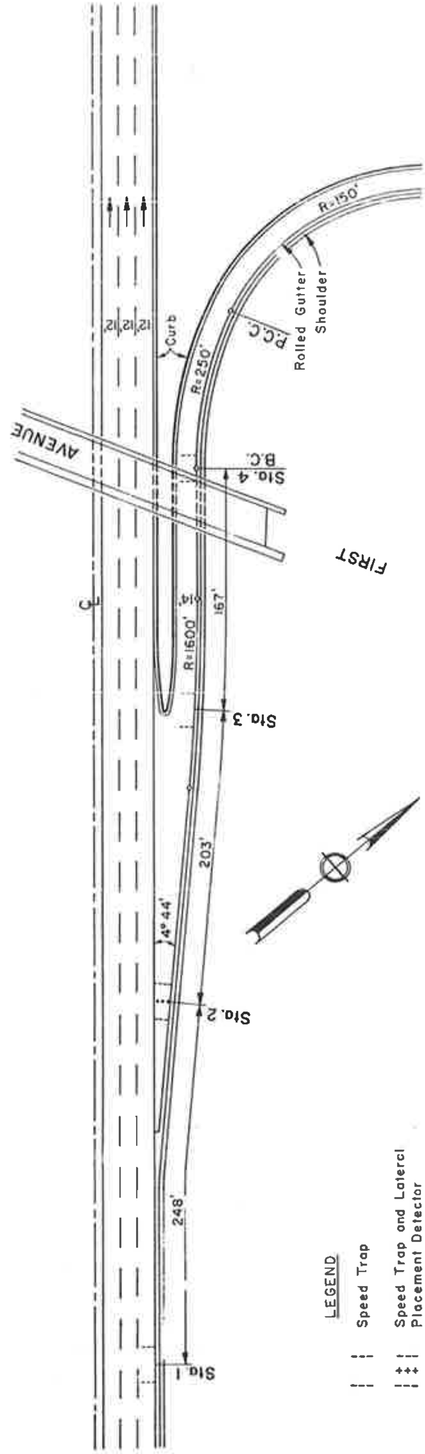
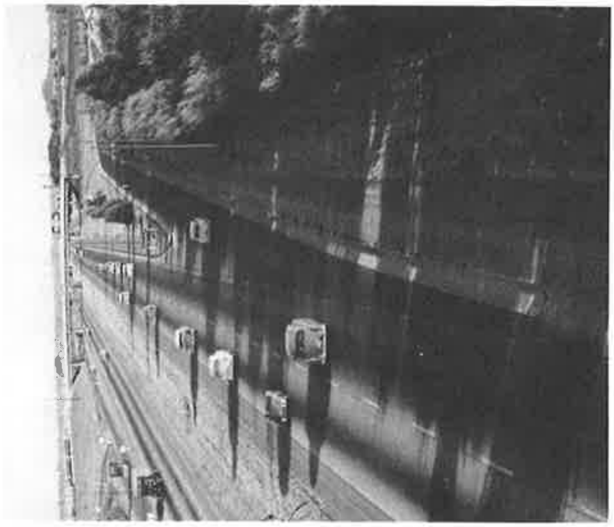


Figure 1. Study site 11, northbound exit ramp to First Ave., Eastshore Freeway, Oakland, Calif.



Sacramento Freeway (US 40) 1,700 ft from the curb nose, and the controlling 250-ft radius curve is 1,200 ft beyond this point. Due to its length, the ramp was split into two sites: site 81 at the location where vehicles leave the freeway, and site 82, the location where vehicles entering Arden Way pass through the controlling 250-ft radius curve.

Site 82.—Location at the end of the Arden Way ramp (Fig. 10).

Data Collecting

The data were obtained with the aid of Traffic Analyzer equipment furnished and operated by personnel of the U. S. Bureau of Public Roads. Four separate units permitted the study of four locations along the ramp simultaneously. Each unit, when actuated by road tubes placed at predetermined locations, recorded on an adding machine tape the time of day to ten-thousandths of an hour and time in hundredths of a second to travel a set speed trap. In addition, operators were present to punch a code into each unit for classifying the type of vehicle.

The stations for study along the ramp were situated as shown in the figures of the various off-ramps. In each study, station 1 was located on the freeway preceding the beginning of the off-ramp. At this station, the operator was required to segregate by code each vehicle that entered the off-ramp. Station 2 was placed where the tapered off-ramp was 12 ft wide. Here, in addition to the speed trap, a placement detector was put in the roadway and the lateral placement of the vehicles leaving the freeway was recorded.

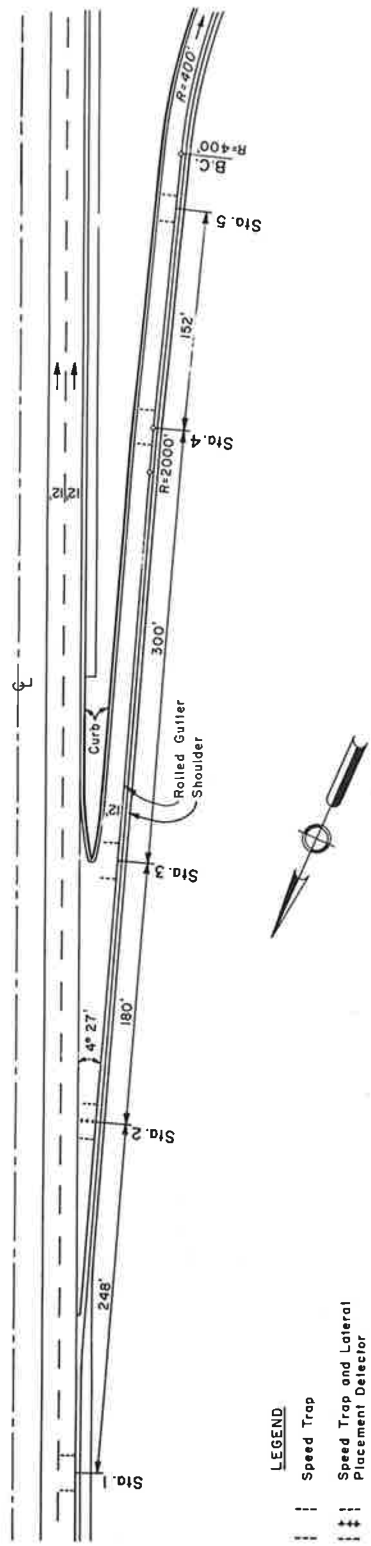
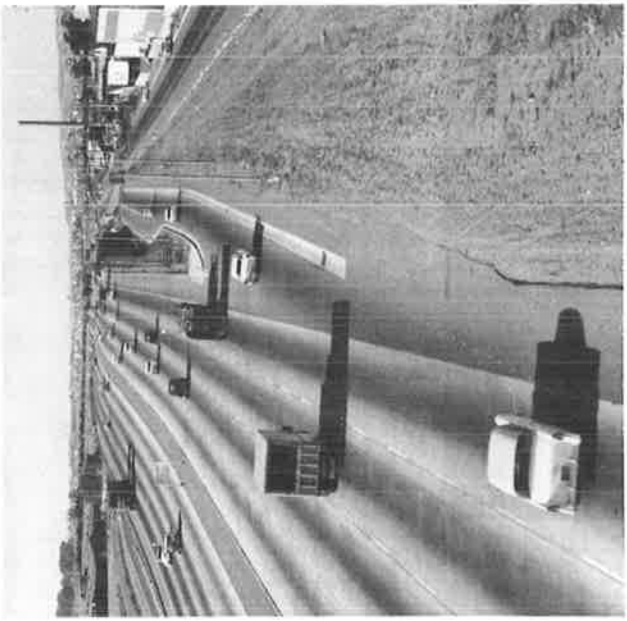


Figure 2. Study site 21, southbound ramp to Winton Ave., Eastshore Freeway, Hayward, Calif.



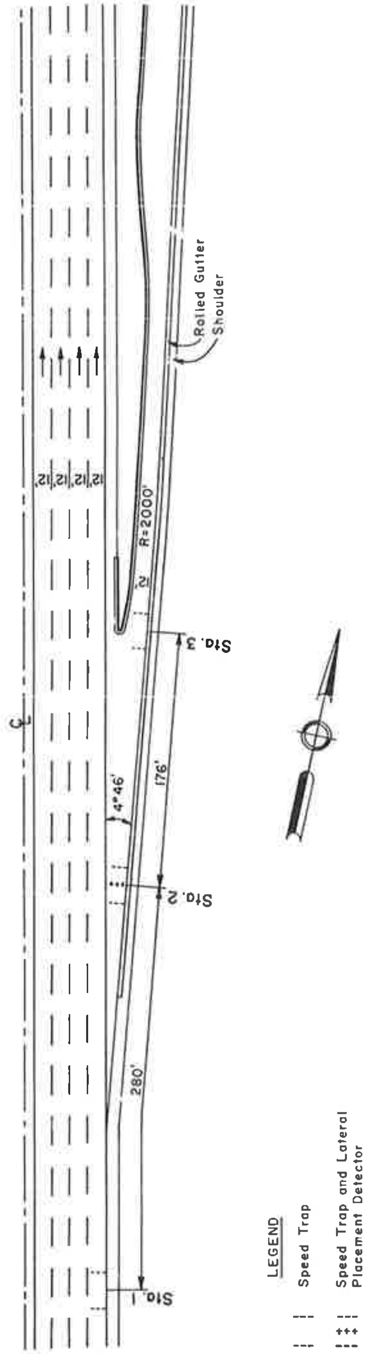


Figure 3. Study site 31, northbound exit ramp to Gilman St., Eastshore Freeway, Berkeley, Calif.

Station 3 was always placed at the nose of the off-ramp. Additional stations were located on the ramps as the geometrics of the off-ramp warranted.

DATA ANALYSIS

The data collected consisted primarily of speeds of all vehicles as they passed the various observation stations.

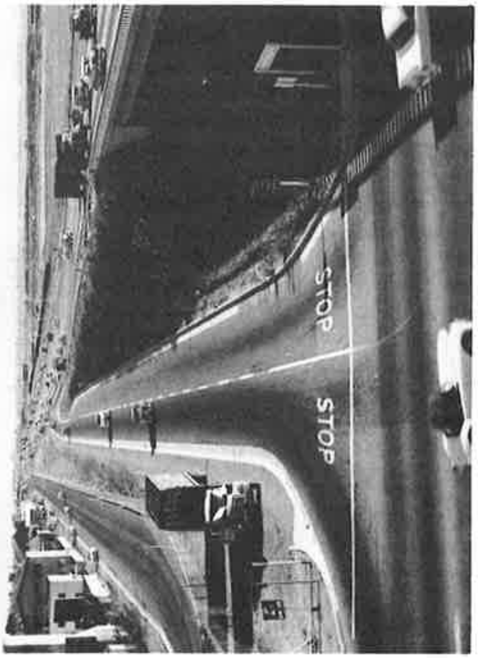
Observation in the field and preliminary analysis of the data showed that ramp traffic behavior was greatly influenced by the characteristics of the traffic flow on the main freeway, especially during periods of congestion on the freeway.

For the purpose of comparing behavior of ramp vehicles at one site with that at another site, it was desirable to eliminate as far as possible the effect of traffic itself. A primary breakdown was therefore made of all data in the following manner:

For every six-minute observation period, the average speed of traffic in lane 1 on the freeway was computed. All data regarding ramp vehicles were then divided into groups, depending on the freeway speed in lane 1.

The groups were in 5-mph increments:

Group	Speed (mph)	Group	Speed (mph)
6	> 50	3	35 - 40
5	45 - 50	2	30 - 35
4	40 - 45	1	< 30



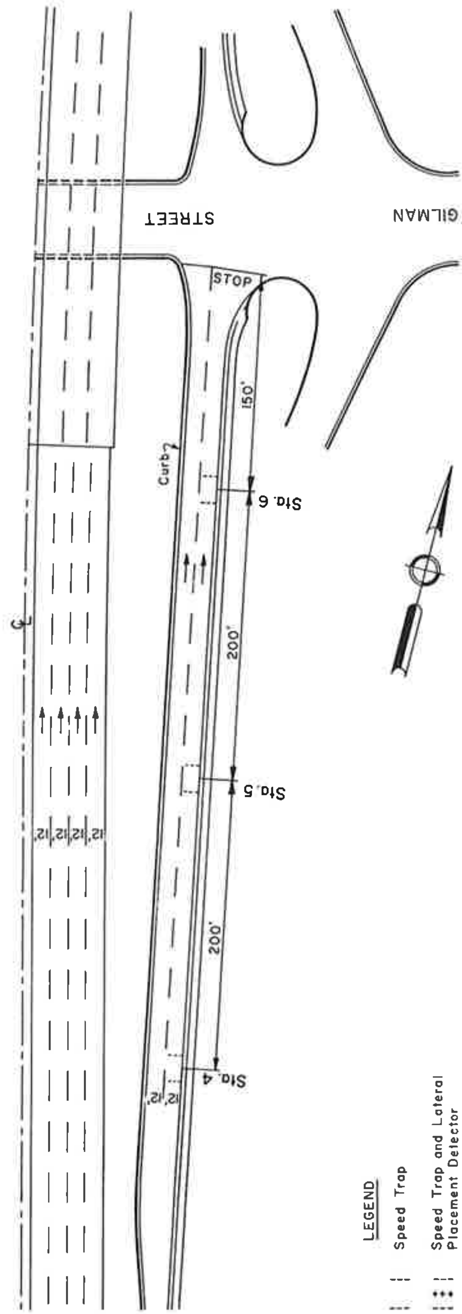


Figure 4. Site 32, terminal condition northbound exit ramp to Gilman St., Eastshore Freeway, Berkeley, Calif.

The speed and deceleration rates of ramp vehicles observed during periods when freeway traffic was congested, would not give the type of data on the operating characteristics of free-running vehicles which must be used as a basis for design and comparison between the various off-ramps.

For this reason, it was decided to base the study on speed group 5 with average speeds between 45 and 50 mph. Except for site 41 where the speeds did not get as high as 45 mph, and at site 81 where speeds were greater than 50 mph, sufficient samples are available in this speed group to indicate a trend in the operating characteristics of the various off-ramps. Table 1 gives the number of vehicles observed.

Placement of the vehicles at station 2, where the off-ramp taper is 12 ft wide, was obtained to compare the lateral placements on the various ramps and the effectiveness of the gore striping.

RESULTS

Speeds Along Tangent Portion of Off-Ramps

Table 2 gives ramp speeds at various locations. Speeds along the tangent portion of the off-ramps were roughly proportional to the length of the ramp tangent; the longer the tangent, the higher the ramp speed. However, where very long tangents are available and alignment is not a control, it appears that there is a psychological maximum of about 46 mph. On these long straight ramps, the speeds at which the vehicles left the freeway were no longer a function of ramp length but of the speed in the outside freeway lane.

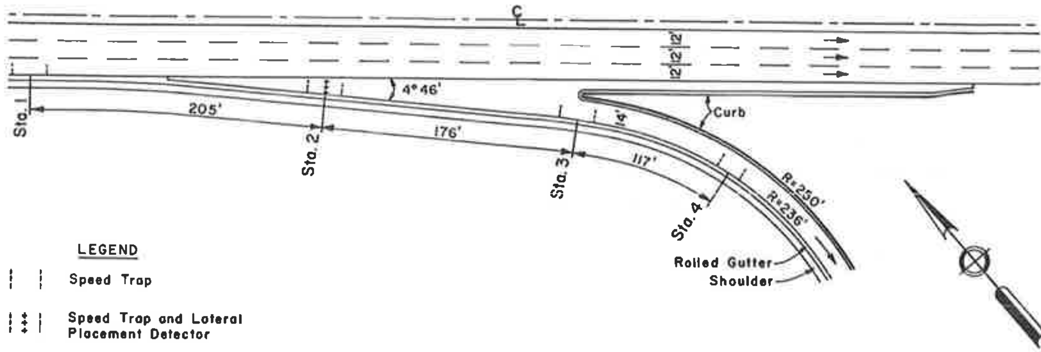


Figure 5. Study site 41, eastbound exit ramp to Lakewood Blvd., Santa Ana Freeway.

TABLE 1

NUMBER OF VEHICLES OBSERVED IN EACH SPEED GROUP

Site	Freeway Speed Group	Number of Vehicles
11	3	495[1]
	4	410
	5	203
21	4	156
	5	269
31	4	212
	5	321
41	2	187
	3	382
	4	593
51	2	454
	3	115
	4	329
	5	295
61	4	60[2]
	5	56[2]
71	4	345
	5	301
81	6	206

[1]Due to congestion on freeway.
[2]Number of samples limited due to counter being out of order.

The table shows that the difference of speed between sites 31 and 81 at the point where the ramp widens to 12 ft is only 0.7 mph and at the curb nose, 0.4 mph. The difference at the beginning of the ramp is 2.5 mph because the through vehicle speed on lane 1 of site 31 is 46.9 mph, as compared to 51.3 mph at site 81. Also, long tangents encouraged vehicles on the off-ramp to accelerate after they left the freeway.

Four speed-distance diagrams for the various off-ramps were plotted. Each diagram shows all study sites, but datum (or station 0) is different for each diagram:

1. Figure 11 uses the curb nose as the distance control. It shows that the speed at the curb nose is related to the distance to the control curve of the ramp.

It also indicates that for a curve having a 400-ft radius, a tangent length of 490 ft beyond the nose is not required for deceleration. However, the long tangent length does result in vehicles leaving the freeway at speeds greater than for shorter lengths.

2. Figure 12 shows speed on the ramp with the distance control at the point where the ramp widens to 12 ft. This can be considered as the location at which the full lane of the ramp becomes available. Here, as in Figure 11, speed is related to the tangent distance to the beginning of the ramp curve with a maximum speed of about 46 mph for high-speed off-ramps.

The speed at the 12-ft point (station 0, Fig. 12) is nearly equal for all tangent distances between 180 and 360 ft. This speed was between 38 and 39 mph, when freeway speeds in the right-hand lane of the freeway were 46 to 47 mph.

It appears that varying the tangent distance between limits of 180 ft (site 41) to 310 ft (site 61) from this point to the ramp curve has little effect on the speed at the beginning of the ramp. Also, when the distance from the 12-ft point to the ramp curve was increased from 310 ft at site 61 to 370 ft at site 11, the deceleration rate decreased. At

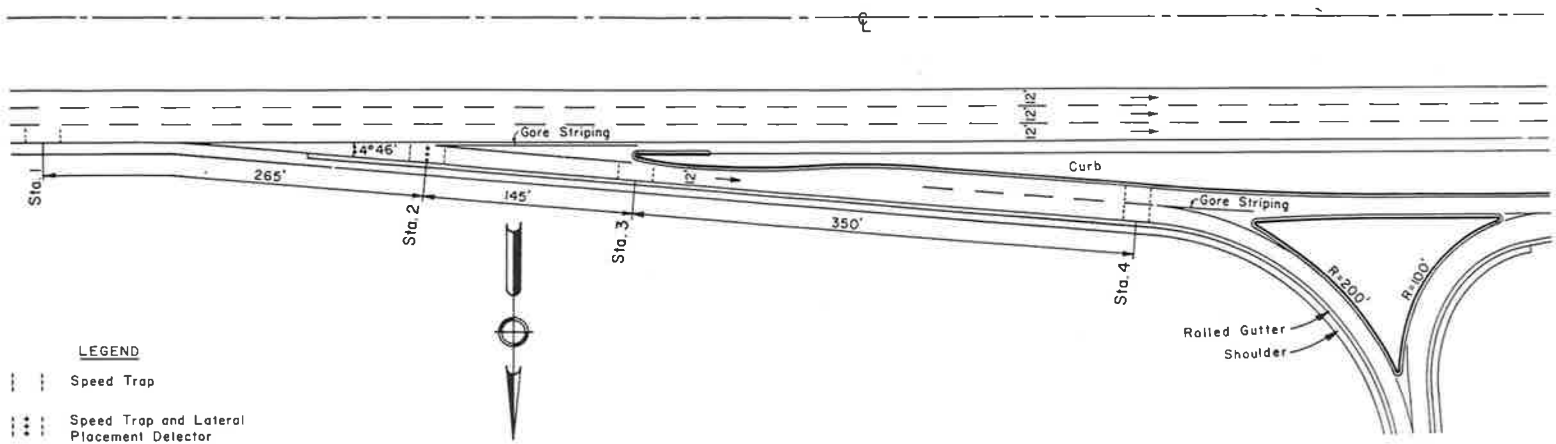


Figure 6. Study site 51, westbound exit ramp to Rosemead Blvd., San Bernardino Freeway.

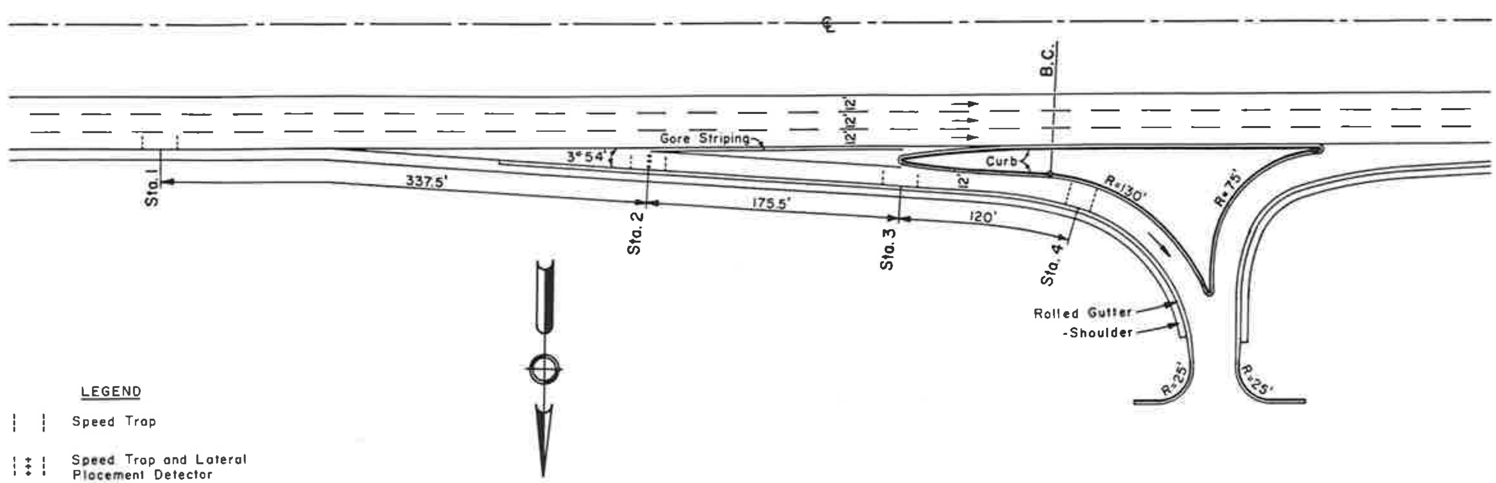


Figure 7. Study site 61, westbound exit to Temple City, San Bernardino Freeway.

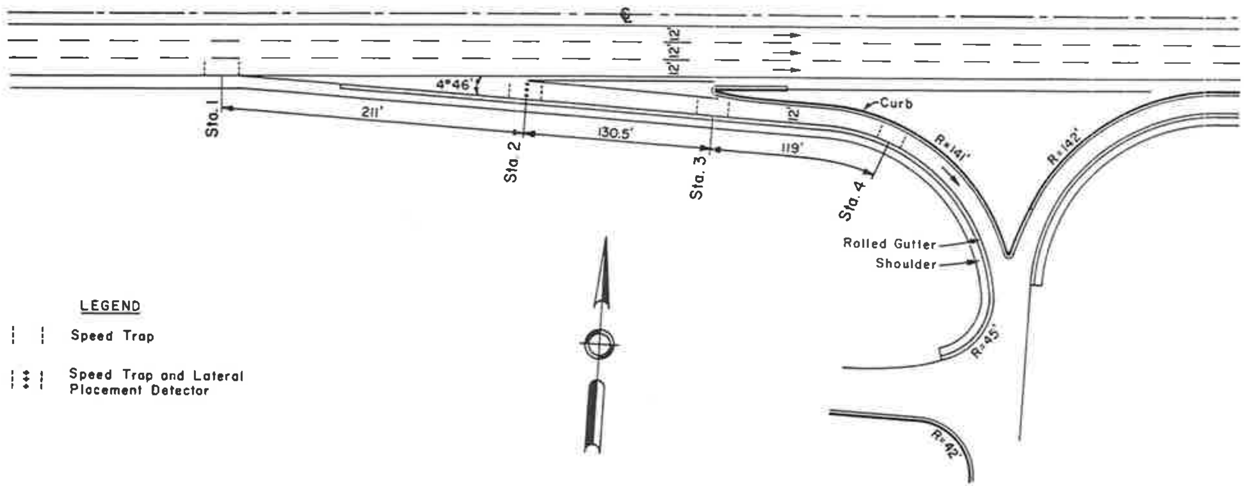


Figure 8. Study site 71, eastbound exit ramp to Vincent Ave., San Bernardino Freeway.

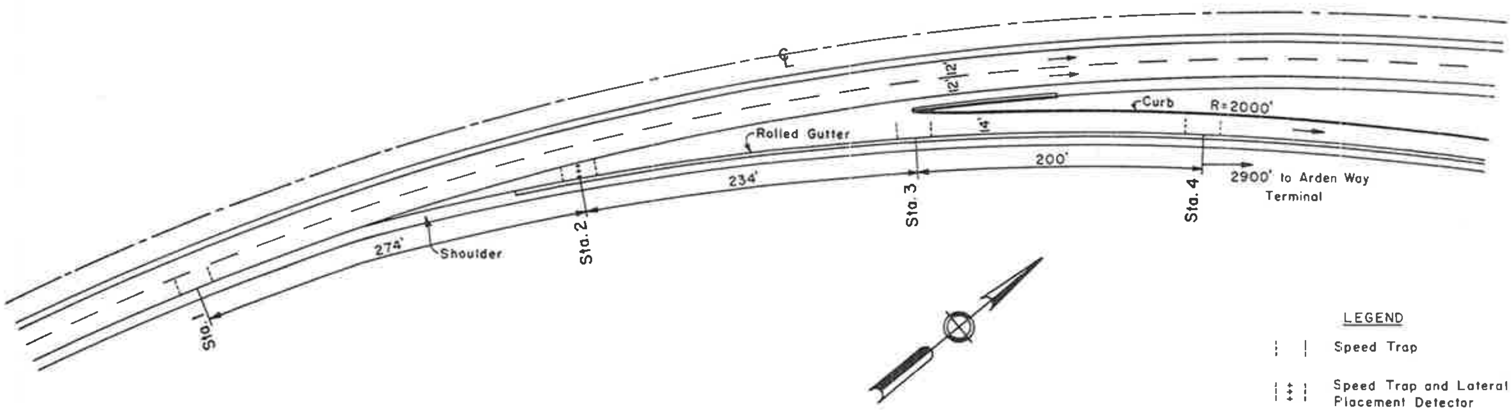


Figure 9. Study site 81, northbound exit ramp to Arden Way, Elvas Freeway, North Sacramento, Calif.

site 11, the average of the higher speed groups at the 200-ft point is 35 mph and at site 61 is 33 mph.

3. Figure 13 shows speed along the ramp with the beginning of the off-ramp taper as the distance control. It also shows that vehicles leaving the freeway begin their deceleration on the freeway between 135 and 220 ft before the beginning of the ramp. This condition prevails without regard to the length of tangent beyond the curb nose. Even on the high-speed Arden Way off-ramp (site 81), there was some decelerating on the freeway.

Ramp speed between the beginning of the taper and the controlling ramp curve is affected by the length of tangent. In addition, the geometry of the ramp, both horizontal and vertical, and the speed of through vehicles on freeway lane 1 have definite effects.

Speed of vehicles leaving the freeway at sites 81 and 41 are definitely affected by the speed of through vehicles on lane 1 of the freeway. By the time the vehicles reach the point where the pavement widens to 12 ft, this effect is not significant.

At site 61, the speed at the beginning of the taper is affected by the downgrade of the freeway. The freeway is on a sag vertical curve from -2.5 percent to level grade. At the beginning of the ramp, it is -1.4 percent. This downgrade results in a higher speed leaving the freeway, and, as a consequence, requires a higher deceleration rate.

At site 11, the geometry of the ramp appears to affect the off-ramp speed. The shape of this ramp is reverse curves, separated by a tangent, and even with a 167-ft tangent length beyond the curb nose, it had the lowest speed for the group at the beginning of the ramp (Fig. 1).

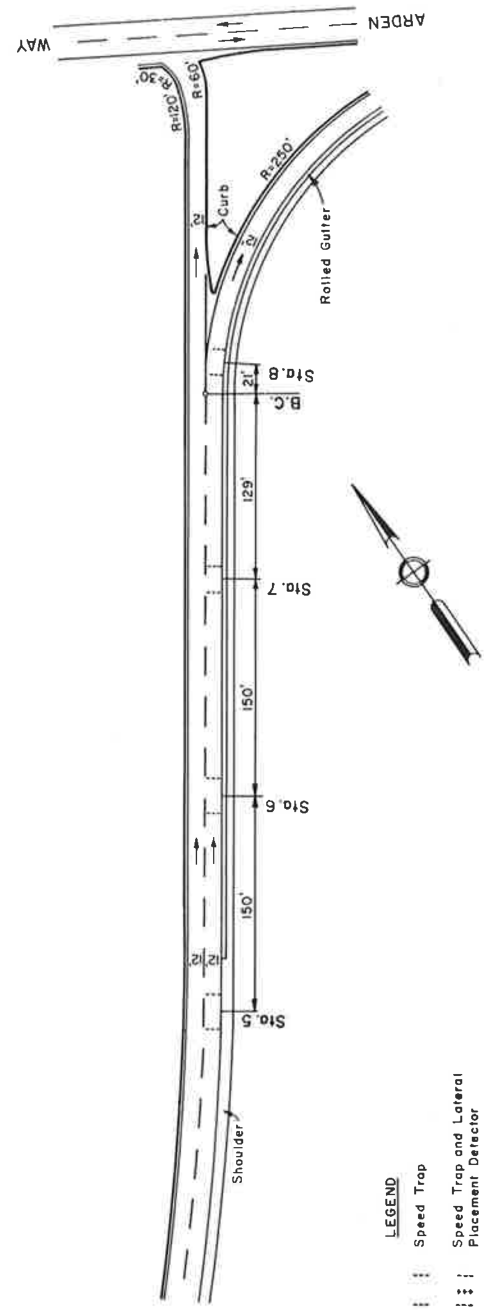


Figure 10. Study site 82, terminal condition northbound exit ramp to Arden Way from Elvas Freeway.

Speed at Ramp Curve

Figure 14 which was plotted with the end of the ramp tangent as the distance control, indicates that drivers do not differentiate between curves having radii varying from 130 to 250 ft. From approximately 150 to 80 ft ahead of these ramp curves, the speeds at sites 11, 61, 71, and 82 vary only about 1.5 mph. Yet, the radius of the curve at end varies from 130 to 250 ft. The high speeds going into the 130- and 141-ft radius curves at sites 61 and 71 are due to the short tangent distance as compared to sites 11, 51, and 82 with larger radius curves and also longer distances to the curves.

TABLE 2

RAMP SPEEDS AT VARIOUS LOCATIONS

Site	Average Speed (mph)					Control at Ramp Terminal
	Lane 1 of Freeway	Begin Ramp[1]	Ramp Widens to 12 ft	Curb Nose	B.C. of Ramp Curves	
11	46.6	41.8	39.2	35.4	29.8	R = 250 ft
21	46.6	45.4	43.8	41.2	36.0	R = 400 ft
31	46.9	45.4	46.2	44.4	---	1,000 ft of ramp still available from nose to stop sign
41	41.6	39.7	38.2	32.8	32.8	R = 250-ft B.C. at curb nose
51N	45.8	43.3	41.3	38.2	26.6	R = 200 ft
51S	45.8	43.3	41.3	39.2	---	600-ft tangent still available
61	45.4	44.5	38.7	32.7	31.9	R = 130 ft
71	46.6	42.2	38.4	32.2	30.7	R = 141 ft
81	51.3	48.0	45.5	44.0	---	3,000 ft of high-speed ramp still available from nose to 250-ft R curve

[1]For purpose of comparison, estimated speed at beginning of ramp listed in lieu of station 1 on freeway, which was variable distance from beginning of each off-ramp.

The speeds of 31.9 and 30.7 mph for 130- and 141-ft radius curves, respectively, cannot be considered in the safe speed range; therefore, these designs should be considered inadequate.

Site 41 and its 250-ft radius curve does not appear to conform with the others. The explanation is that the freeway at this point is on a +2.3 percent grade and drivers are approaching the curve at a higher speed and utilizing the grade for deceleration. The B.C. of the 250-ft radius curve is located at the curb nose and therefore the shorter tangent length results in the higher speed going into the curve.

Site 82 has the highest deceleration rate approaching the ramp curve. At this site, which has a 250-ft radius curve, the vehicles have been traveling at about 42 mph for at least 1,000 ft and are not affected by the deceleration from the freeway or the length of tangent.

Site 32 in Figure 14 indicates the distance required to come to a complete stop at the end of an off-ramp at a diamond-type interchange. From this observation, it is concluded that a vehicle driver traveling at 33 mph can comfortably decelerate to a stop in 300 ft, if he is aware of the stop requirement. It also indicates that it is comfortable to stop from 28 mph in 150 ft.

Lateral Placement at Station 2

Figure 15 shows the location of the left tire at station 2 where the ramp widens to 12 ft. The range of samples used was in the 10-90 percentile group of all vehicles using the off-ramp during the study. Gore striping, as used, does tend to guide the vehicles as indicated by sites 51, 61, and 71, where the decelerating vehicles make full use of the ramp as designed. The other sites did not have gore striping at the time of the study.

Figure 11 shows that gore striping at sites 61 and 71 results in an increased rate of deceleration where there is a ramp curve a short distance beyond the curb nose. On

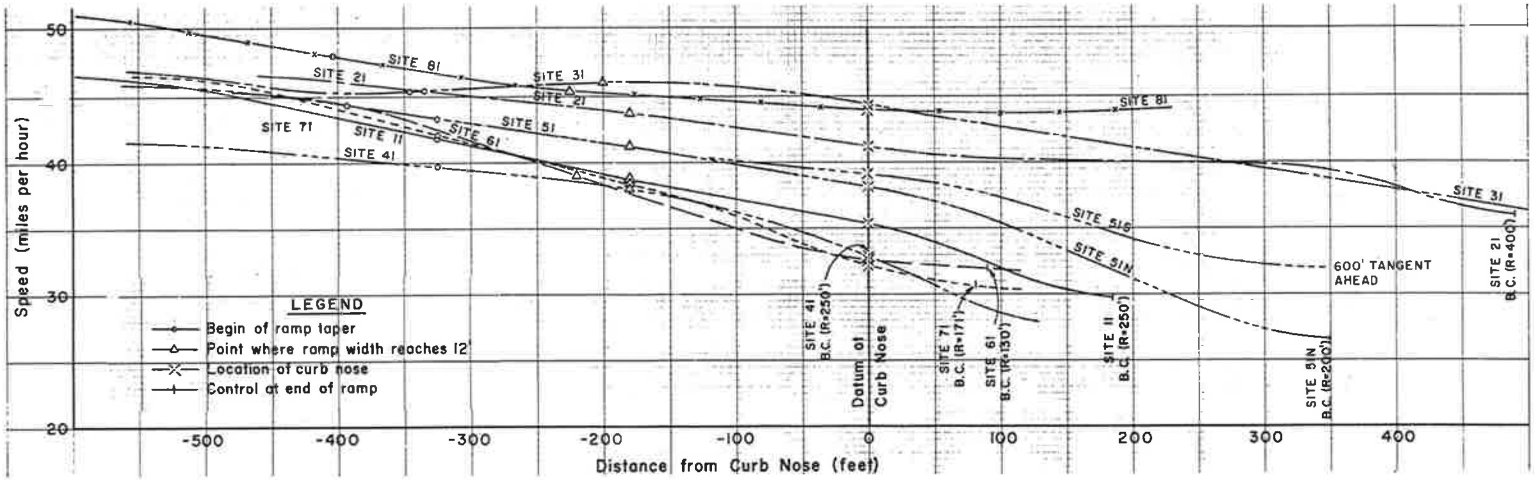


Figure 11. Speed along off-ramp related to distance from curb nose.

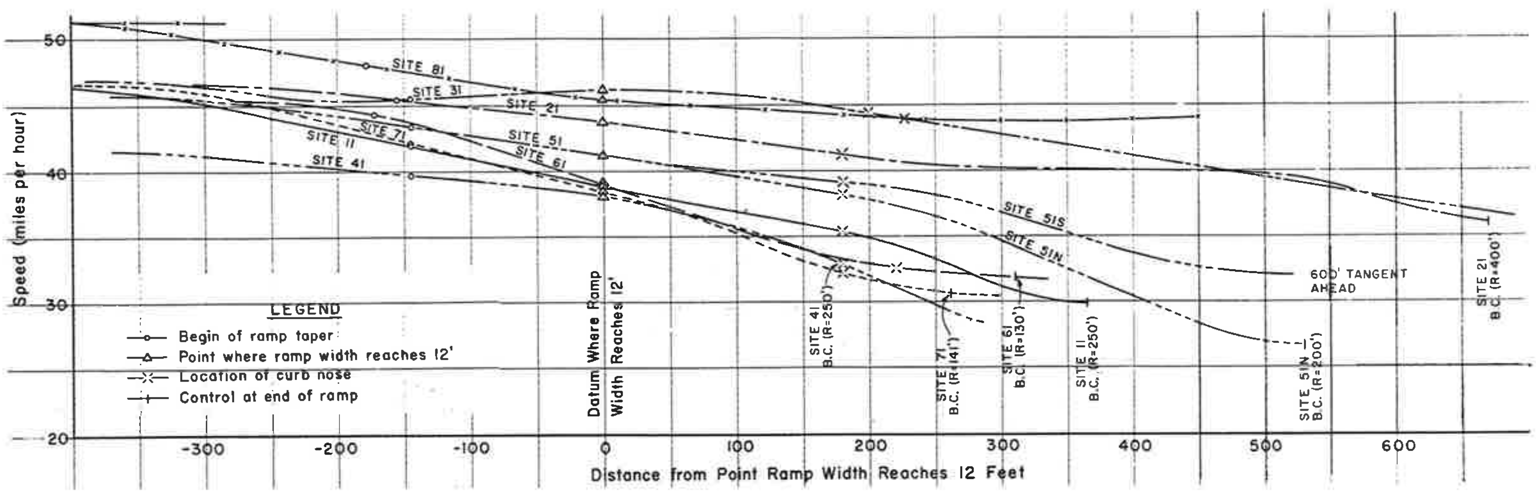


Figure 12. Speed along off-ramp related to location where ramp widens to 12 ft.

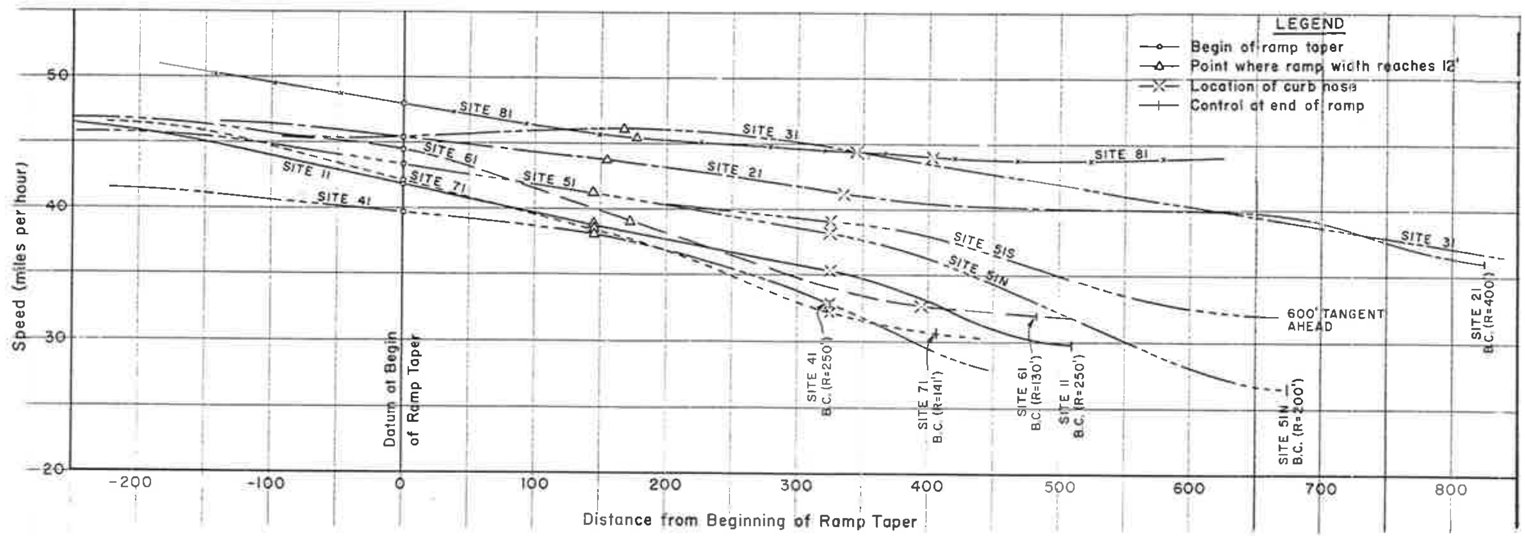


Figure 13. Speed along off-ramp related to distance from beginning of ramp taper.

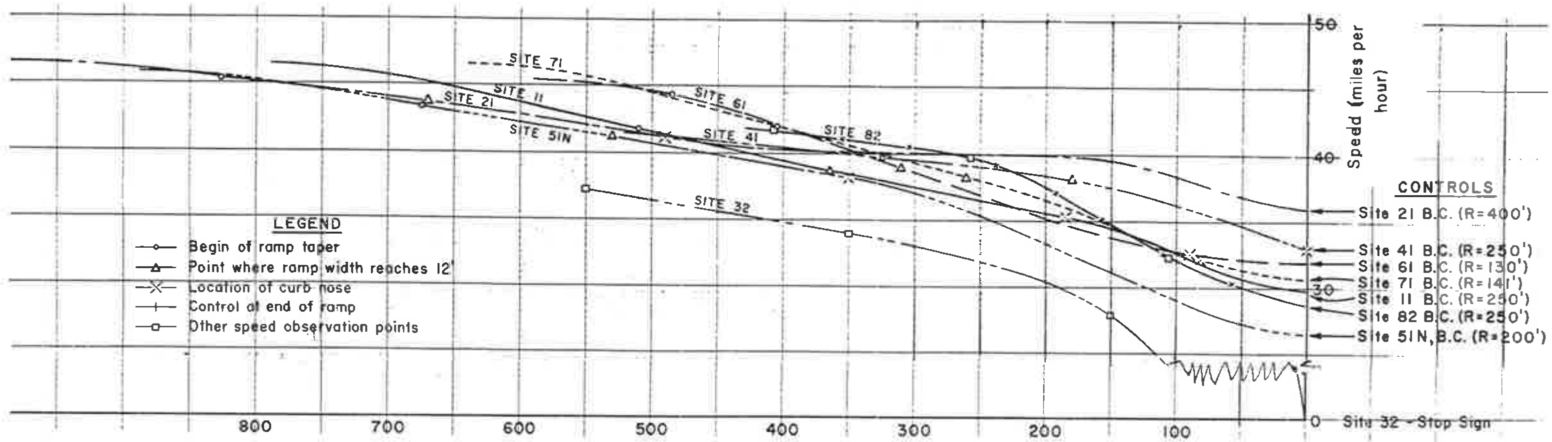


Figure 14. Speed along off-ramp related to distance from end of ramp tangent.

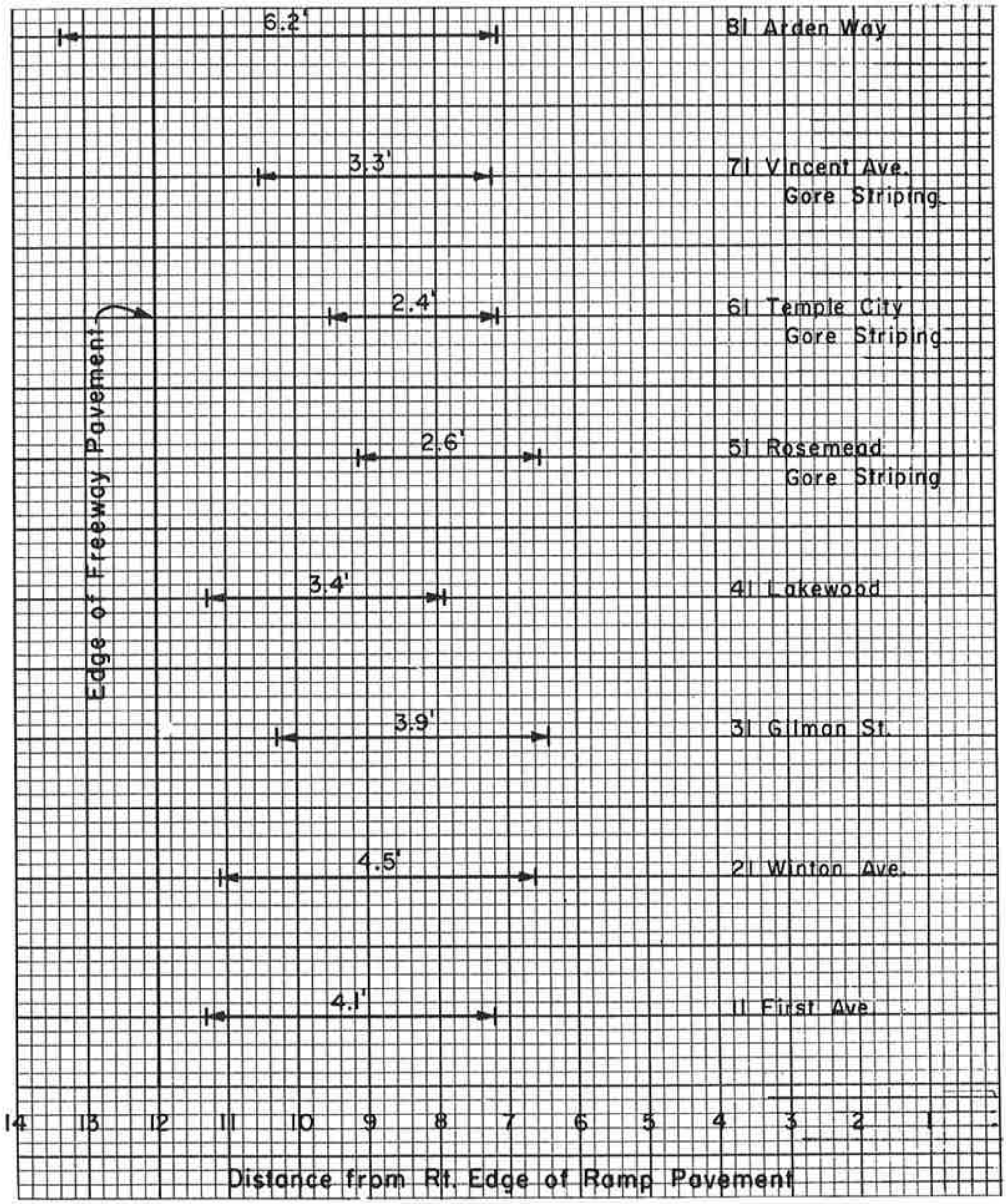


Figure 15. Ramp placement, range of left tire 10-90 percentile.

diamond-type off-ramps and long tangent off-ramps, gore striping does not appear to affect the decelerating rate.

CONCLUSIONS

The following conclusions and recommendations were drawn from this study and observation of other off-ramps.

The speed of vehicles using the deceleration lane is determined by three factors in combination: (a) the speed of vehicles in the outside lane of the freeway, which influ-

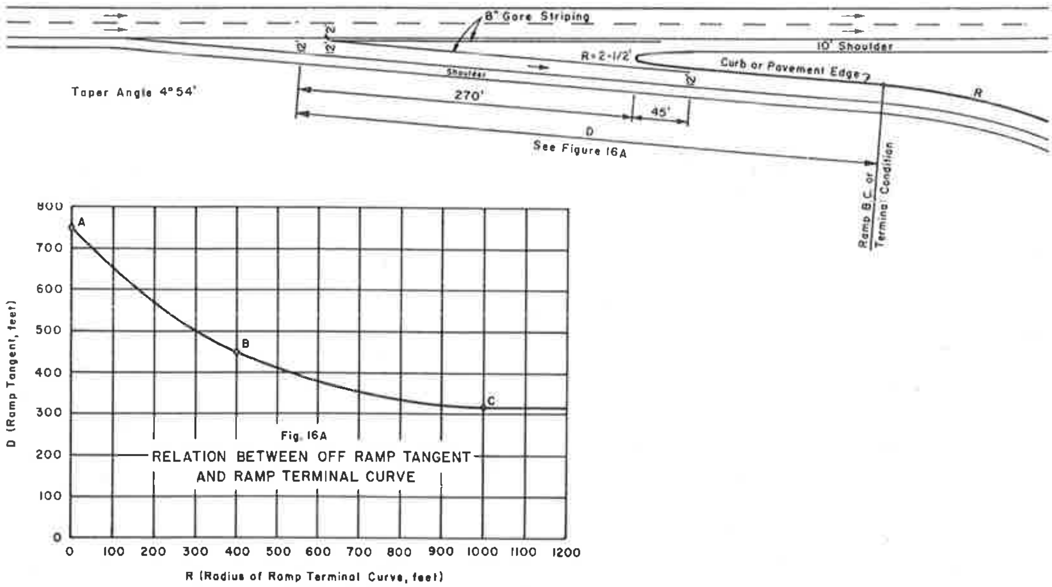


Figure 16. Suggested exit ramp.

ences the exit speed, (b) the length of tangent available to decelerate, and (c) the ramp curve or terminal which determines the speed to which the ramp traffic must decelerate.

The ideal off-ramp design is the arrangement of the diverging area to provide the least interference to through traffic and a length of tangent to encourage high-speed exit. In this regard, because the average driver decelerates before entering the off-ramp, relative speed of the vehicle leaving the freeway from lane 1 and the through vehicle on lane 1 is an important criterion for judging the design. Every effort should be made to provide a high-speed design, but it must be kept in mind that this is not a branch connection, and the geometrics should not entice through vehicles onto the ramp. A definite cue must be retained to indicate that this is an off-ramp. This cue is provided by the angle of deflection of the ramp.

On leaving the freeway, the driver should be provided with a length of tangent sufficient to decelerate to the speed of the terminal control. It was found that if this length is exceeded, vehicles will assume a steady speed, and accomplish the necessary deceleration in the last few hundred feet preceding the curve or "Stop." The length of tangent is controlled by the ramp terminal curve. The driver does not discriminate between a 130- and a 250-ft radius curve. He is just as likely to enter a 130-ft radius curve at a higher rate of speed than a 200- or a 250-ft radius curve (Table 2).

Figure 12 shows that the longer the tangent distance, the higher the ramp speed. Also, a ramp tangent length up to 310 ft does not increase vehicular speeds on the ramp (sites 61, 71, 41). Tangent length of 365 ft (site 11) just begins to indicate an increase in ramp speed.

The curve for site 21 indicates that when 670 ft of tangent precedes a 400-ft radius curve, a steady speed is maintained for more than 200 ft; in other words, this is more distance than would be used for deceleration. Considering that 200 ft was not used in decelerating, a length of 470 ft would appear to be adequate.

SUGGESTED STANDARD OFF-RAMP

From the preceding, it is seen that the length of tangent from the 12-ft point should be at least 450 ft when the ramp curve has a radius of 400 ft. Shorter distances are found to result in significantly lower speeds at the curb nose, which are reflected in interference with freeway traffic as the ramp vehicles leave the freeway. It may also be assumed that distances less than this amount result in unnaturally high rates of deceleration. This would have a significant effect on the unfamiliar driver who is more likely to overrun the curve if he is required to use an unnatural rate of deceleration than if natural deceleration could be obtained. In making a traffic behavior study, almost all of the vehicles observed are "familiar" drivers and a certain amount of rationalization is necessary to interpret this behavior in terms of accident-producing situations.

The observed data provided a foundation for determining a natural deceleration distance for curves with a 400-ft radius; namely, 450 ft for decelerating to 37 mph after leaving the main line. They also provide a foundation for determining a natural deceleration distance; namely, 300 ft for decelerating from 33 mph to a stop (site 32). The curve for site 32 in Figure 14 does not show what the natural distance for decelerating from 37 mph to a stop would be, because the faster group of drivers were only going 33 mph when they really started to decelerate. It is believed that the 300-ft distance is more significant in determining where the drivers decide to start coming to a stop than the 4-mph difference between 37 and 33 mph. It is known, of course, from many other studies, that braking distance under forced conditions is much less than this amount; the objective of this study is to try to ascertain a "natural" distance which should result in fewer misjudgments and accidents than some lesser distance.

Having established 450 ft as the natural distance for a 400-ft radius and 750 ft as the natural distance for a stop, it follows that for curves between 130 and 400 ft in radius, some in-between distance is required. (To fit topographic controls, diamond-type interchanges usually provide tangent length in excess of the 750-ft requirement.)

It is also recognized that for curves with a 1,000-ft radius or flatter, no distance is needed for deceleration, and the minimum distance is, therefore, the distance required to cue the driver that he is approaching an off-ramp. This can be accomplished by retaining a standard geometric design for all off-ramps. This design should be common to a point 45 ft beyond the curbed nose to include the curb offset flare.

In Figure 16, Point A (the natural distance for a stop), Point B (the natural deceleration distance for a 400-ft radius curve), and Point C (when deceleration distance is not required) were plotted. A curve was passed through these points from which the ramp tangent, D, can be selected for any ramp terminal curve, R.

In the design of ramp terminal curve, R, it is recommended that 400-ft be held as a minimum for all exterior ramps of interchanges. It is also recommended that radii less than 130 ft be considered a channelizing turn at a stop sign, and treated as a "stop" situation.

A combination of the preceding recommendations has resulted in the off-ramp suggested in Figure 16. The deflection angle of the ramp is controlled by the width necessary in the gore for ground-mounted guide signs. Pavement marking ahead of the curb nose is recommended to delineate the left-hand edge of the ramp, while providing a traversable target for vehicles leaving the freeway. In addition to the horizontal geometrics, it is also very important that the driver has a good view of the ramp and, if possible, the ramp terminal control.

The suggested off-ramp is being recommended as a standard design for all conditions. Although quantitative observations were not made on traffic behavior at higher freeway speeds, general observations indicate the exiting vehicles generally decelerate to the 50-mph range before leaving the freeway, and this is believed to be unavoidable as well as unobjectionable. This was partially observed at site 81 (Table 2). Lane 1 of the freeway at site 81 averaged 51.3 mph, approximately 4.7 mph faster than at a similar high speed at site 31. However, at the location where the ramp widens to 12 ft the vehicles at site 81 were 0.7 mph slower. It therefore seems that the off-ramp design will be adequate at the higher speeds found on some rural freeways.

Off-ramps are not as subject to variation in design as entrance ramps, but standardization to a high type of design would result in the use of the ramps as the designer intended, would eliminate doubt on the part of the motorist, and would simplify engineering.

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

DONALD O. COVAULT, Associate Professor, School of Civil Engineering, Georgia Institute of Technology, and
ROBERT R. ROBERTS, Traffic Engineer, Wilbur Smith and Associates

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.

Paper sponsored by Committee on Freeway Operations.

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

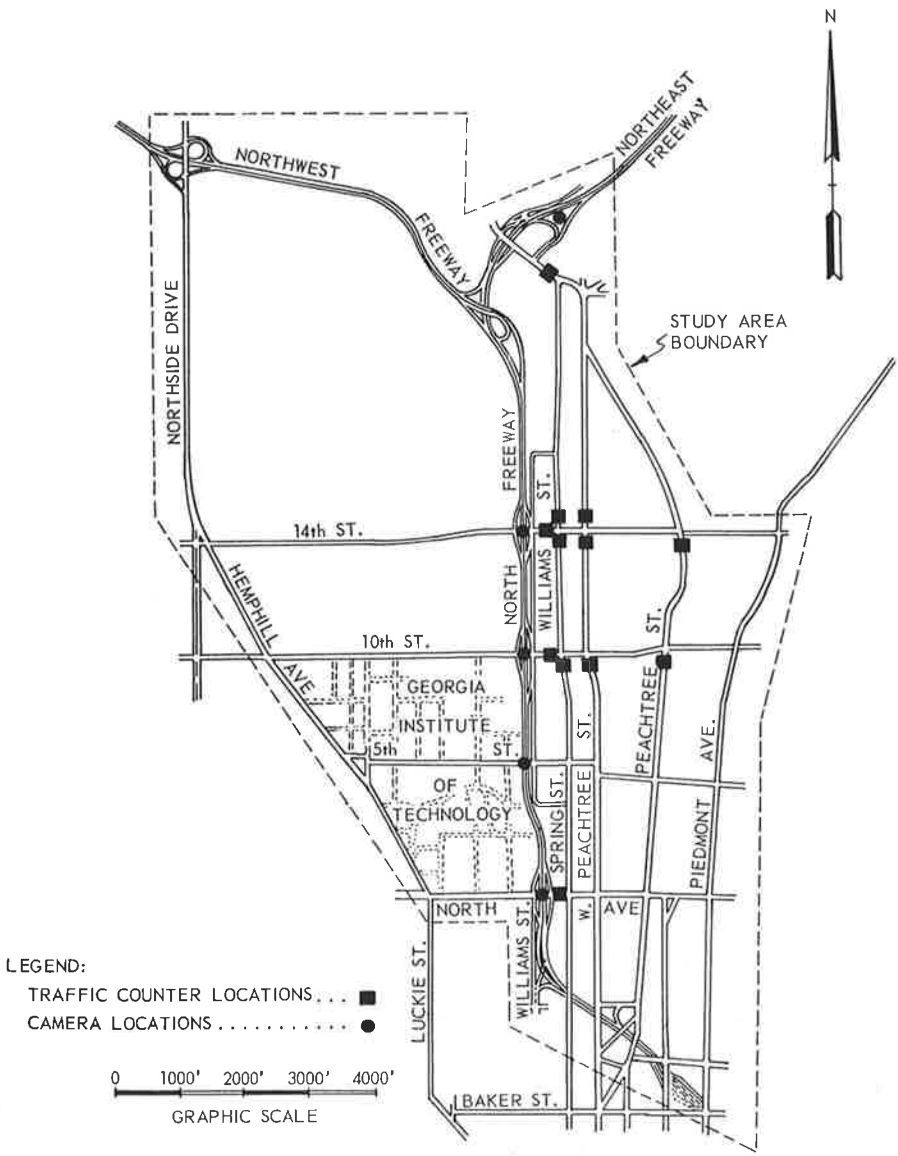


Figure 1. Study area.

TABLE 1

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

<table>
<tr><th rowspan="2">Location</th><th rowspan="2">No Ramps Closed, Normal Operation</th><th colspan="3">Northbound On-Ramp Closed</th></tr>
<tr><th>North Avenue</th><th>10th Street</th><th>14th Street</th></tr>
<tr><td>Williams Street[1] – North Avenue</td><td>0.089</td><td rowspan="2">0.797</td><td>0.089</td><td>0.089</td></tr>
<tr><td>North Avenue – 10th Street</td><td>0.708</td><td rowspan="2">1.067</td><td>0.708</td></tr>
<tr><td>10th Street – 14th Street</td><td>0.359</td><td>0.359</td><td rowspan="2">1.250</td></tr>
<tr><td>14th Street – Peachtree Street</td><td>0.891</td><td>0.891</td><td>0.891</td></tr>
<tr><td>Peachtree Street – Piedmont Road</td><td>1.458</td><td>1.458</td><td>1.458</td><td>1.458</td></tr>
</table>

[1] Left-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 3^0. 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.

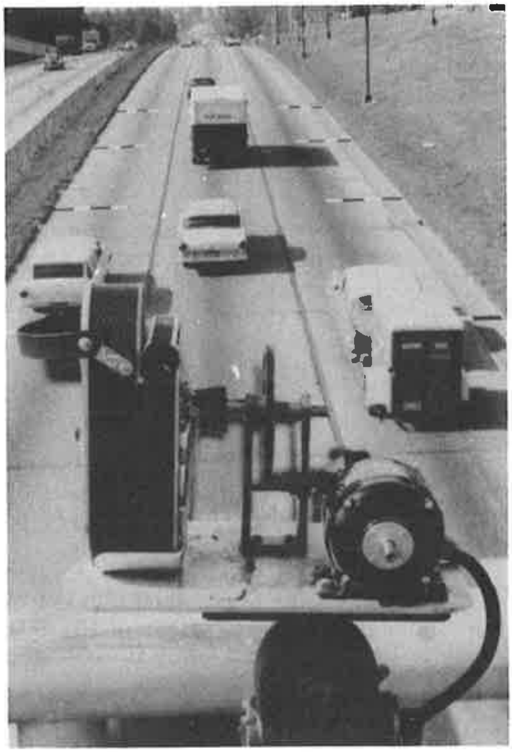


Figure 2. Field location of time-lapse movie camera at 10th Street, looking north.

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 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	North Ave. closed	10th St. closed	Normal operation
5th St.	14th St. closed	North Ave. closed	Normal operation	10th St. closed
10th St.	10th St. closed	14th St. closed	North Ave. closed	Normal operation
14th St.	10th St. closed	Normal operation	14th St. closed	North Ave. closed

[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	14th St.	10th St.	5th St.	North Ave.
North Ave. closed	14th St.	10th St.	North Ave.	5th St.
10th St. closed	14th St.	10th St.	North Ave.	5th St.
14th St. closed	14th St.	10th St.	5th St.	North Ave.

[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

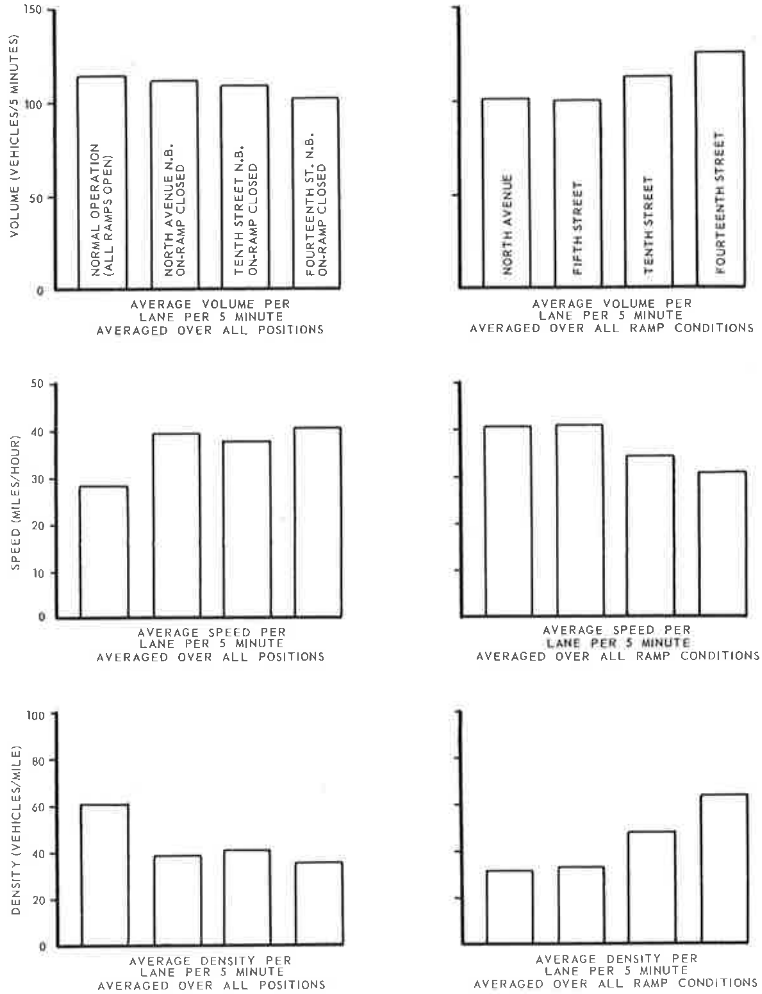


Figure 4. Average volume, speed, and density per lane per 5-min time interval on North Freeway averaged over all positions and ramp conditions.

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

[1] No 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.

[1] No 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

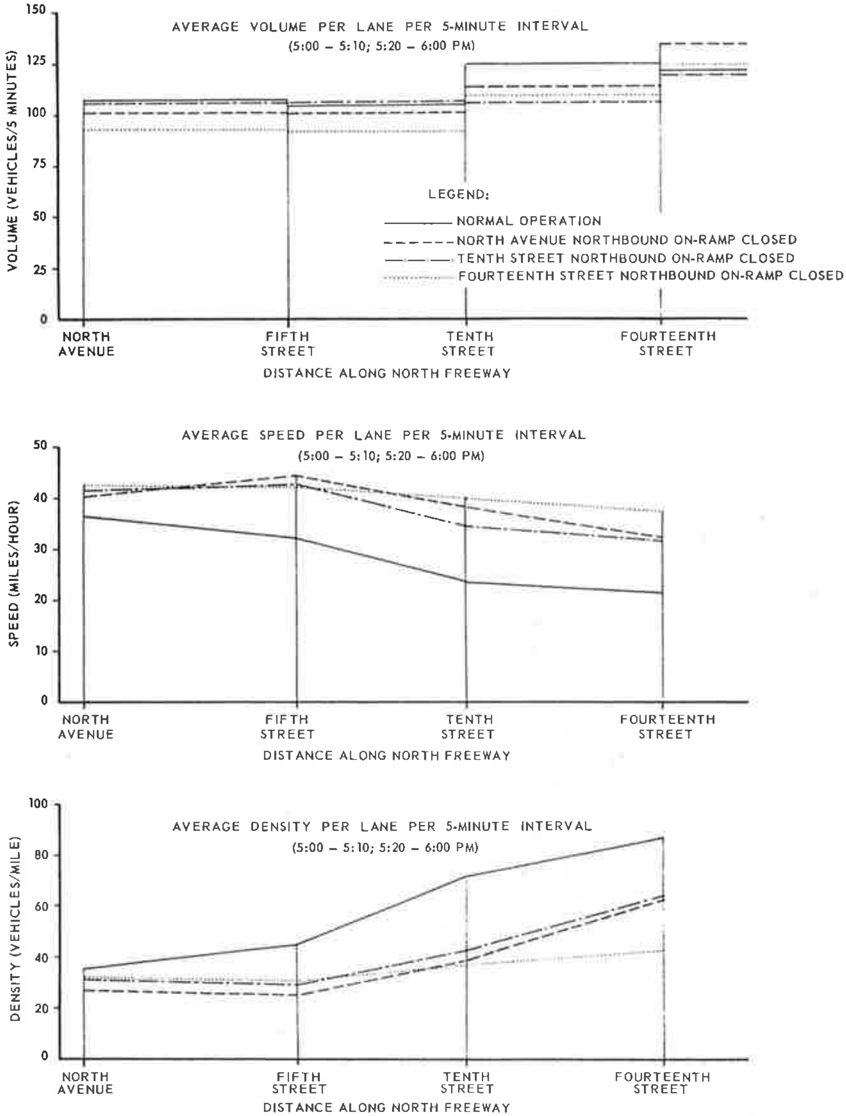


Figure 5. Average volume speed, and density per lane per 5-min time interval on North Freeway.

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.

REFERENCES

1. Carlson, R. J., "Effectiveness of Ramp Closure During Peak Hours." Proc., 13th Annual Western Section Meeting, Institute of Traffic Engineers (July 1960).
2. Covault, D. O., "Time-Lapse Movie Photography." Traffic Eng., Vol. 3, No. 6 (March 1960).
3. Duncan, D. B., "Multiple Range and Multiple F. Tests." Biometrics, Vol. 11, No. 1-4 (1955).
4. Greenshields, B. D., "The Density Factor in Traffic Flow." Traffic Eng., Vol. 30, No. 6 (March 1960).
5. Hall, E. M., and George, S., Jr., "Travel Time—An Effective Measure of Congestion and Level of Service." HRB Proc., 38:511-529 (1959).
6. Keese, C. J., "Improving Freeway Operation." Proc., 13th Annual Western Section Meeting, Institute of Traffic Engineers (July 1960).
7. Leisch, J. E., "Spacing of Interchanges on Freeways in Urban Areas." Jour. Highway Div., ASCE, Vol. 85, No. HW4, Pt. 1 (Dec. 1959).

8. Peterson, J. M., "Freeway Spacing in an Urban Freeway System." Jour. Highway Div., ASCE, Vol. 86, No. HW3 (Sept. 1960).

9. Covault, D. O., and Roberts, R. R., "The Influence of Ramp Spacing on the Traffic Flow Characteristics on the Atlanta Freeway and Arterial Street System." Annual Report 1, Engineering Experiment Station, Georgia Institute of Technology (Dec. 1961).

Development and Evaluation of Congress Street Expressway Pilot Detection System

ADOLF D. MAY, JR., PATRICK ATHOL, and WILLIAM PARKER, respectively, Director, Assistant Director, and Supervisor of Instrumentation, Expressway Surveillance Project, Illinois Division of Highways, Oak Park, Ill.; and
JAMES B. RUDDEN, Technical Advisor, Thompson-Ramo-Wooldridge, Canoga Park, Calif.

• IN APRIL 1961, an expressway surveillance project was established as a part of the research program of the Illinois Division of Highways, under the supervision of the Bureau of Research and Planning. The project is being financed with Highway Planning Survey funds made available through the Federal-Aid Highway Acts with the State, Cook County, and the City of Chicago contributing the necessary matching funds. An advisory committee, consisting of representatives of the four cooperating agencies was appointed and meets frequently to review the progress of the experimental work of the staff and to review and advise on the steps recommended for future experimental work.

The project objective is to conduct operational studies, locate critical points, determine causes of congestion both qualitatively and quantitatively, investigate ways to improve flow, and measure resulting benefits to traffic. The activities of the project staff also include the investigation of electronic techniques for the surveillance of traffic behavior and the detection of stalled vehicles. The ultimate objective being to reduce congestion on expressways in the Chicago area by means of automatic traffic control and information measures.

This paper reports on the development and evaluation of a pilot detection system which has been installed on a 5-mi section of the westbound Congress Street Expressway between Cicero Avenue in Chicago and First Avenue in Maywood.

This system consists of traffic detectors on the ramps and on the expressway at selected locations along the study section, interconnection to the central office, and analog computers, map display, and various data recording devices including a paper punch tape output.

PRELIMINARY OPERATIONAL STUDIES

Study Techniques

The initial study was a machine-count program to measure the volumetric traffic flow characteristics of the Congress Street Expressway. These counts were summarized by the daily 24-hr total (Fig. 1), and the individual hourly totals (7 to 8 AM and 4 to 5 PM). The data collection consisted of machine counts at all the entrance and exit ramps and four mainline (expressway through lane) counts. The mainline counts at all remaining locations were derived by the addition and subtraction of ramp movements.

Another measurement made was the speed of vehicles at the points where volume counts were taken. Speeds were recorded at frequent intervals before, during, and after the peak-volume period of the outbound traffic. A moving vehicle technique was used whereby the speedometer reading was noted at each 0.2-mi increment of the odometer. This study was conducted using standard employee automobiles, and as a control check, the times and distances of passing each overpass were recorded. The distance between overpasses within the study section was accurately determined, and observations from

Paper sponsored by Committee on Freeway Operations.

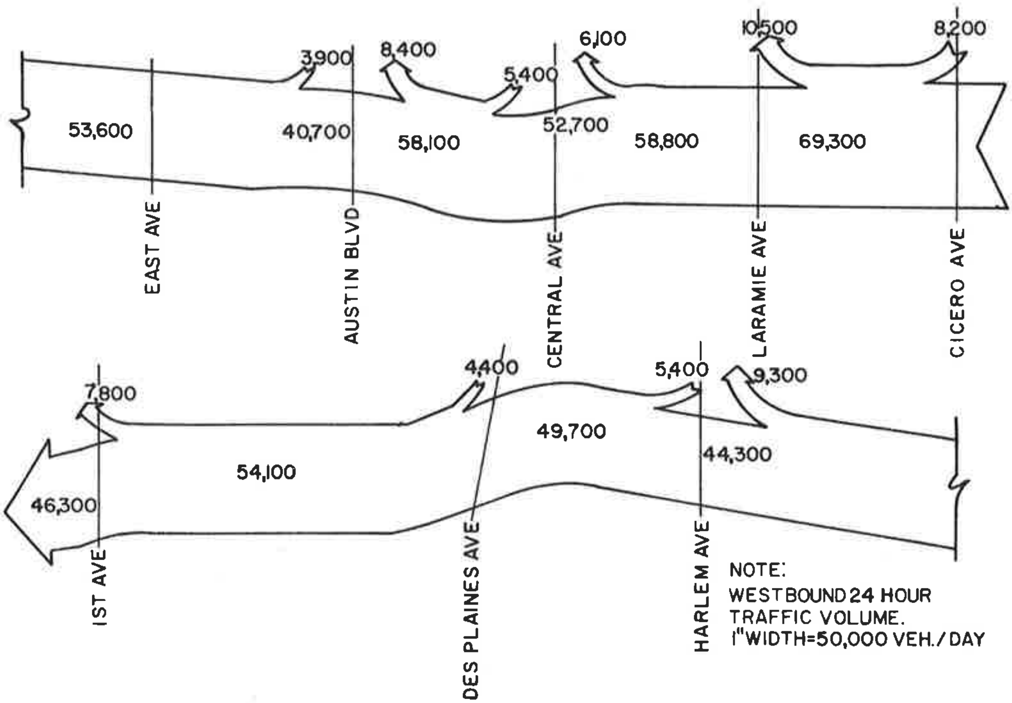


Figure 1. Traffic flow map.

individual runs were interpreted in this light. From the results of these speed runs, contour maps were prepared (Fig. 2) which showed the speed changes, by time and location, occurring along the expressway, as well as the duration of those speed changes. The speed contour maps showed the locations at which speed changes first occurred and also the manner in which those speed changes were reflected back along the expressway.

Aerial photographs recorded the density of traffic within the expressway section under study. A light aircraft flew over the expressway and took aerial photographs with a 50 percent overlap. From these photographs, technicians counted the number of vehicles present on the roadway between overpasses. These determinations yielded a measurement of density at a certain point in time. Similarly with speed, density contours were prepared (Fig. 3). Inasmuch as only one density reading was taken between structures, for each pass of the aircraft, the density contours, as compared to the speed contours, were less sensitive to small variations along the roadway.

From a review of the operating characteristics of the expressway shown in the volume flow map and the speed and density contour maps, it was decided to locate a more detailed ground photography study at eight locations at the western edge of the westbound congestion area. The choice of the westerly location provided that, with possible operational improvements through the study area, the downstream section would be adequate to handle the increased traffic flow.

At the eight stations selected, cameras were mounted on the overpasses, and time lapse photographs were taken at the rate of 60 frames per minute. On each frame the dial of a watch appeared in one corner and served as a time reference. The individual watches were in turn related to a master timing device and assured time comparisons for traffic at various locations.

From the time-lapse photographs individual speeds, density, and volumes were measured on a per-lane basis. Individual speeds were measured from the films by recording the distance traversed by a vehicle relative to markings on the shoulder, the time to travel such a distance being determined from the speed of the film. Average density was determined by counting the vehicles within a 400-ft trap and averaging five

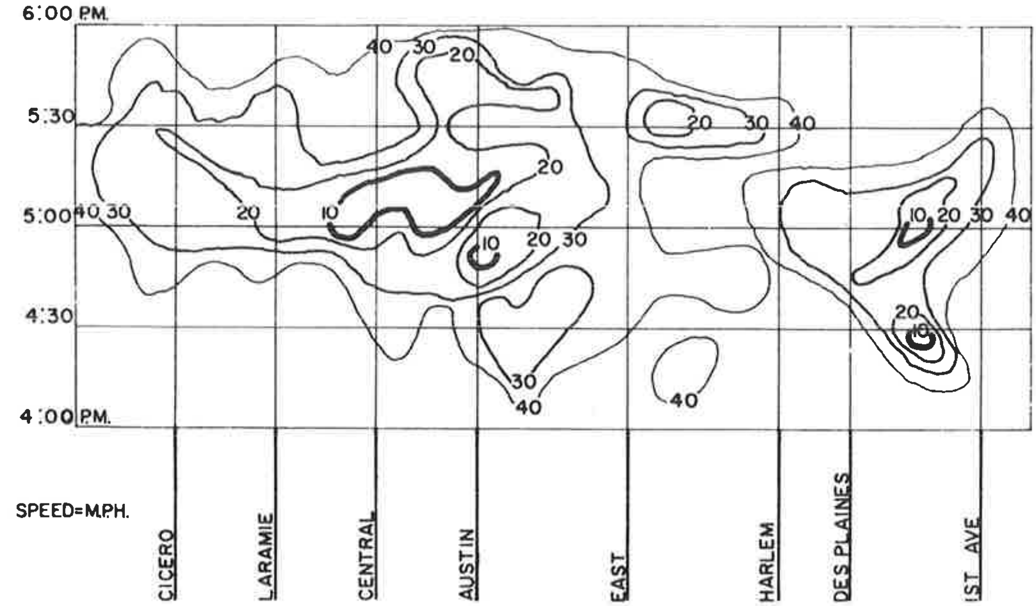


Figure 2. Speed contours.

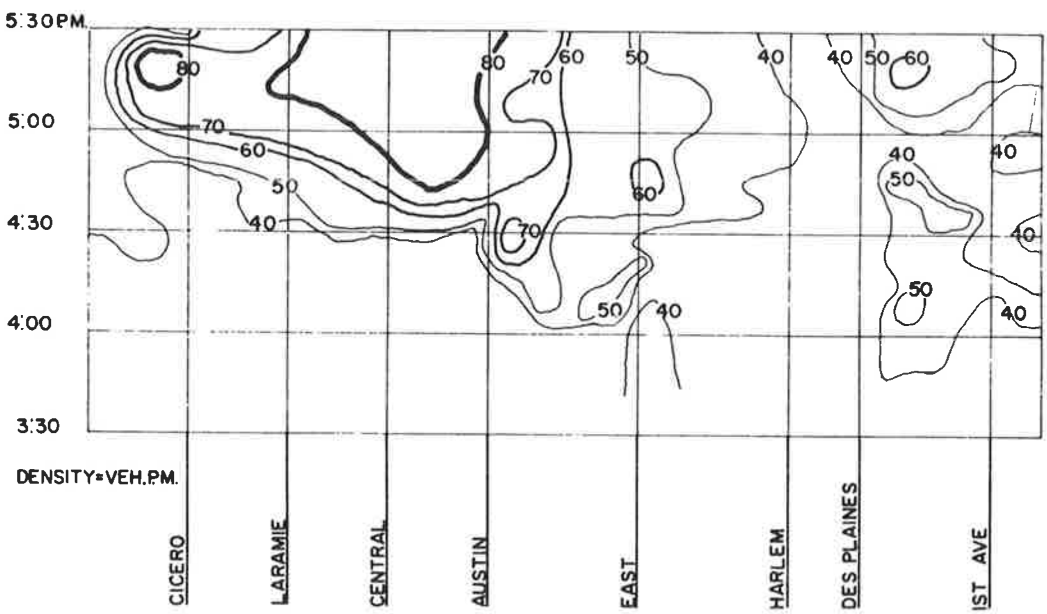


Figure 3. Density contours.

such determinations per minute. Volume was a straight forward count of vehicles passing a line. These measurements result in a space mean speed and a space mean density over a similar section, and also a point volume within the measuring section. In this analysis of the time-lapse filming, over 200,000 individual vehicles were analyzed from a selected total of 32 hr of filming free from technical faults in both exposure and timing.

Results

Selection of Study Section.—The study section chosen was the most westerly section experiencing lengthy and irritating traffic delays, and included a wide variety of geometric design features. The upstream limit of the study section occurs to the downstream side of an exit ramp, thus the traffic reaching the study section is reduced in an amount equal to the ramp volume. Detailed studies showed the downstream limit of the study section to be a location downstream from a constriction point and operated free of reflected congestion during detailed studies. With the limits of the study area defined by stations not causing operational difficulties, it is possible to isolate the extent of operational difficulty experiences within the study section.

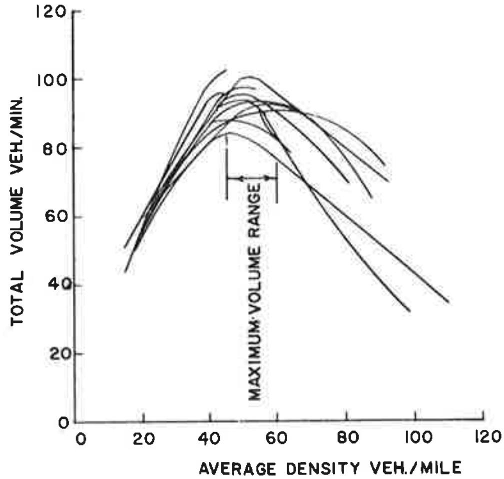


Figure 4. Average density related to total volume.

Selection of Measurements.—The selection of parameters to be measured was tempered by the limitations of the manufactured detection equipment available. Speed and volume detectors are available, from several manufacturers, though varying in accuracy. On the other hand, density as measured on a space mean basis is not available while the available point density system calculates density from measured speed and volume. Lane occupancy is an additional measurement which is presently available from manufacturers and is a point measurement of the percentage of time that a vehicle is present under the detector. Lane occupancy may be compared to calculated density, the unit "percentage occupancy" varies with the type of vehicle present in the traffic stream and is dependent on the length and corresponding speed of the individual vehicles.

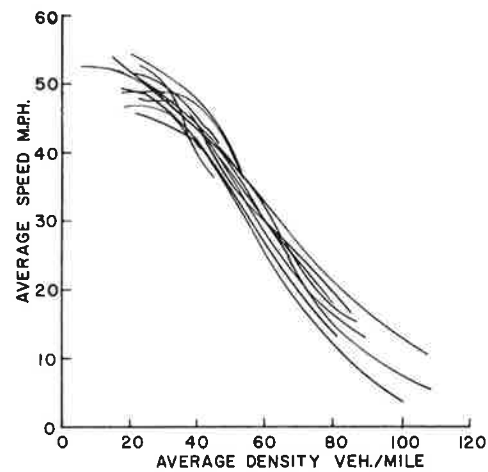


Figure 5. Average speed related to average density.

The selection of measurements was based on the results of the ground photography, and a comparison of the manufactured detection systems presently available. Observation of the speed and density profiles indicated that as operations deteriorated there appeared to be inverse relationship between these measurements—speed decreased as density increased.

The interrelationships between speed, density, and volume as measured from the film were examined on the basis of the minute averages; these were arithmetic averages of the individual data collected within the minute. Each of three pairs of these measurements was directly compared in Figures 4, 5, and 6. It was evident from the data that the interrelationships depended on the station location relative to a trouble spot. Downstream operations do not directly break down under observation, but reflections upstream often cause breakdown. The trouble spots themselves appear to cover an area of expressway and are not easily pinpointed. Along a section of highway, very often the downstream station for a trouble spot becomes the upstream station for another trouble

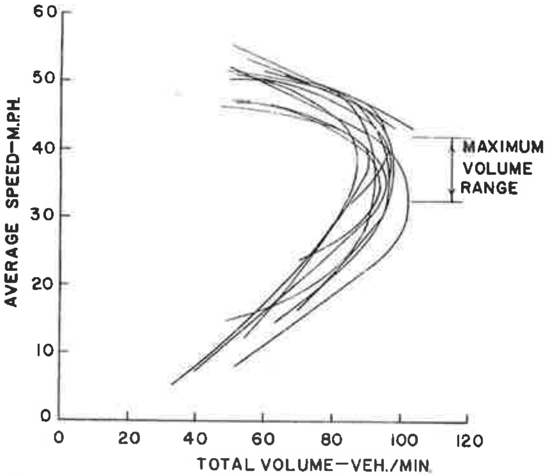


Figure 6. Average speed related to total volume.

spot and there is often considerable difficulty in isolating conditions. This is also the reason for individual stations changing their characteristics. The eight camera stations compared were at two downstream locations, three upstream locations, and three trouble spots.

From the summary graphs, the closest relationship appeared to exist between speed and density; linearity in this relationship yields a parabolic curve of volume-density. However, a concave relationship between speed and density was also noted, and this closely approximates a constant volume. Again, there was a dependence on the stream location of the station as to which characteristic predominated; upstream tended more closely towards the constant volume situation.

As a summary of average conditions at various locations along the stream of traffic, the generalized traffic flow diagram of Figure 7 was prepared. This generally divides traffic operations into three zones, which may be briefly described as constant speed, constant volume, and constant rate of change of volume with density. Interpreting the diagram, it may be stated that zone 1 (constant speed) is an operation in which the speed of vehicles is determined by the facility itself and that the volume matches the demand. Zone 2 represents impending poor operations; average speed drops but the volume rates may be sustained at a high level. In zone 3, both speed and volume rates decrease, and this in itself may serve as a definition of congestion.

The effectiveness of individual measurements to describe and predict traffic operations was noted as follows: Zone 1 shows the limitations of speed to indicate the proximity of traffic operation to zone 2. Small changes in speed may correspond to larger changes in traffic operations. Volume rates zones 1 and 3 may be of equal magnitude and cannot be differentiated; however, density appears indicative of traffic operations over the complete spectrum of traffic operations.

Manufacturers at present offer volume as a "free" measurement included with their speed occupancy or density detector systems. The systems to review, therefore, would be all three measurements (speed-occupancy-volume) or two measurements (occupancy and volume or speed and volume). Speed detection requires movement of traffic and is less reliable as operations approach stoppage. Measurements of occupancy tend to increase the stoppage, and their accuracy remains at about the same level as with free-flowing traffic.

The measurement proposed for the pilot detection system was a volume-occupancy system with an additional, limited number of speed detectors that afford the opportunity to verify the preliminary parameter selection and give added flexibility in designing future studies.

Placement of Detectors

Longitudinal.—The selection of detector stations was restricted to structures over the expressway upon which detector heads could be conveniently affixed. Within the limits of the study section defined, the detector stations were selected in the following manner. The limits of the study section fixed the locations of two stations, Cicero Avenue in the east and First Avenue in the west. The next station selected was at East Avenue which was chosen as a base, at a location away from ramps and situated at approximately the halfway point of the study section. The final selection of the remaining four stations was predicated on the location of trouble points associated with inferior traffic operations, pinpointed from the photographic study, and also from the moving vehicle studies.

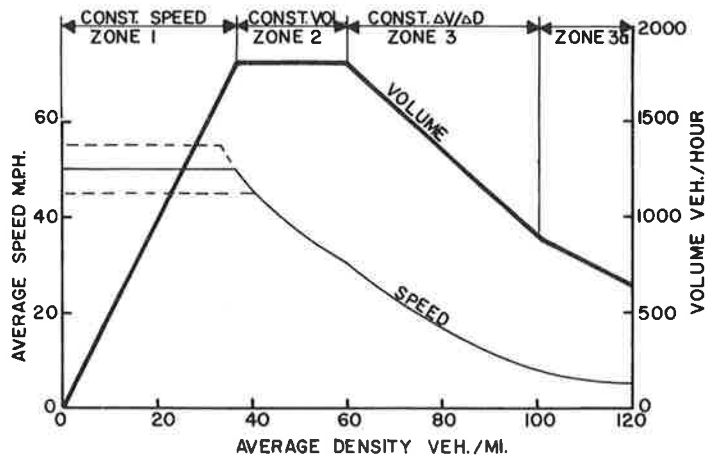


Figure 7. Generalized traffic operations.

In summary, the choices were as follows: the study limits of Cicero Avenue and First Avenue, the base station at East Avenue, and four trouble spot locations at Austin Boulevard, Central Avenue, Harlem Avenue, and Des Plaines Avenue.

Lateral.—The selection of the pilot detection system was in part based on the aim of the earliest possible prediction of congestion, defining congestion as both a lessening in speed of operation and the volume rate. The lateral placement of detectors was determined on the basis of traffic operations up to congestion. In this manner it was noted that the center lane of the three-lane sections, both before and up to congestion, gave the highest reading, or equal to the highest reading of occupancy across the pavement; exceptions may exist under extremely light traffic, but in such cases there would be no concern for impending congestion. For the four-lane section, both the center lanes appeared comparable and gave the highest occupancy readings before and at the commencement of congestion. In general, it was decided to locate the detector heads over the center lanes. To verify the choice of the center lane, one station was equipped with three complete detector systems and a second station was similarly adapted utilizing spare equipment. To pursue a comprehensive research study, detector heads were located over all remaining lanes, and switching units were installed at the roadside to facilitate detection on any one lane, as required by the different studies. As a result, detection is available on every lane; however, only one lane may be used at any one time, with the exception of the base station at East Avenue.

Roadside detectors were located on all entrance and exit ramps. Mainline volumes at individual stations may be calculated by the addition and subtraction of ramp volumes to the corresponding volumes recorded at the East Avenue base station. In addition, making use of the ramp detector chassis and spare equipment, any station may be activated to yield simultaneous reading of detectors on all the mainline lanes.

The overall system features reasonable economies in the quantity of equipment installed, and yet the built-in flexibility of the system permits more detailed studies and analysis as needed.

SURVEILLANCE EQUIPMENT EVALUATION

To have a basis for making a decision in the selection of vehicle detectors, interconnect methods, traffic flow computers, and data-collecting equipment suitable for use in an expressway surveillance system, the expressway surveillance project initiated an equipment evaluation study.

Invitations were sent to all manufacturers known to be interested in traffic surveillance or traffic-control equipment. Two manufacturers who had traffic flow computer systems replied and were willing to demonstrate their equipment to the project for testing. Included with the demonstration equipment were graphic recorders and digital tape recorders.

Three types of traffic flow computers were tested, and are referred to as follows:

1. V.S. (measured volume and speed).
2. V.O.S. (measured volume and occupancy and computed speed, on line; that is, computation within the equipment's own computer).
3. V.S.D. (measured volume and speed and computed density on line).

Measurements

One week was devoted to data gathering with each manufacturer's equipment. The detectors were installed on the Paulina Street bridge over the westbound lane of the Congress Street Expressway. Interconnection between the detectors and computers was made by means of a voice grade telephone pair, used for both data transmission and voice communication.

To record accurately the volume, speed, and density of the traffic as it was being measured and recorded by the manufacturer's computer equipment, two types of film records were made. A Keystone 16-mm camera was set up on the Paulina Street overpass to film the westbound expressway traffic. The ground photography camera exposed one frame of film per second. At the same time, aerial photographs were taken from a helicopter flying at 2,500 ft over the test site. The 4 by 5 aerial camera exposed one frame per 12 sec.

During the period in which the equipment was undergoing tests, its outputs were recorded by graphic recorders and printed digital paper tape recorders furnished by the manufacturers. The data recorded were manually transferred to code sheets and then punched onto IBM cards. Actual traffic conditions which existed during the test period were determined by using a Perceptoscope (a single-frame projector) to view the time-lapsed films. Through the use of the Perceptoscope the staff technicians were able to take speed measurements and volume counts from the films with a high degree of accuracy.

Density measurements were made from the aerial photographs by viewing the negatives with a transparency projector and counting the vehicles in the test area. The volume, speed, and density data were then punched on IBM cards.

Although both manufacturers' equipment was tested at the same location and at the same time of day, it was not tested on the same dates; therefore, the data from the equipment cannot be compared directly. Furthermore, no attempt was made to interpolate the data to make them applicable to conditions different from those actually encountered.

Equipment

The V.O.S. computer gathered its data through an ultrasonic presence detector. The input to the V.O.S. computer was a pulse generated by the detector relay contact closure. The closure time is equal to the period that the pavement beneath the sensing head was occupied by a vehicle. The total count was displayed by means of a five-digit counter. The count data were integrated over a selected time base resulting in an analog volume display calibrated in vehicles per minute.

The input pulse length data were similarly integrated to provide an analog voltage, calibrated as percent of lane occupancy.

Speed was computed on line as a function of percent lane occupancy, volume, and assumed vehicle length. Two vehicle lengths were used: one for commercial vehicles and another for passenger vehicles as determined by the classification feature of the detector.

The V.S. computer gathered its data through an ultrasonic motion detector, using the doppler principle.

The detector output was a frequency proportional to the individual vehicle speed. The V.S. computer then transformed the doppler frequency into a voltage proportional to the individual vehicle speed. These individual voltages were integrated resulting in an averaged lane speed.

The V.S.D. computer gathered its data through a radar motion detector using the doppler principle. The detector output indicated the passage of each vehicle by producing a frequency proportional to that vehicle's speed. The doppler output was then fed into a speed and impulse translator which in turn produced two outputs, volume pulses and speed information. The volume computer and classifier received impulses from the speed and impulse translator which were then integrated and displayed on an analog meter calibrated in percentage of maximum vehicles per lane per hour.

The speed information was fed into two speed computers. The first computer displayed the speed of the last car on one meter and the root mean square lane speed on another meter. The second speed computer received its input from the first unit and displayed arithmetic average speed and the mean deviation on its meters. Means were included for adjusting the sample size and for connecting the meter current to graphic recorders on the volume and speed computers.

The output of the speed and impulse translator was also fed into a density computer. The computer integrated these inputs into two running averages and displayed the ratio as vehicles per miles. The output of the density computer was also recorded on an analog graph.

After completion of the data-gathering period the project staff manually transferred the data from the paper chart to graphs to code sheets. This information was punched onto IBM cards, and processed in a high-speed computer. The results yielded photographic data with the analog quantities of the equipment.

The laborious transfer of information from analog charts to a form acceptable to a data-processing system strongly indicated the need for a compatible data-gathering method. Therefore, the staff at this time began an investigation of data-collecting methods. Of the several methods investigated, punched paper tape seemed the most suitable, as three of the cooperating agencies were already using digital computers requiring this mode of input.

With the data-evaluation work completed, the task of determining which of the three systems would most closely meet the needs of the project was undertaken.

Summary

The three systems tested all showed a high degree of accuracy, although the system using the ultrasonic presence-type detector tested out slightly better than the other two.

This method of detecting traffic flow also gave promise to be more economical in a large surveillance system. The outputs of several detectors generating contact closures may be transmitted over one telephone pair using some form of tone equipment or telemetering, whereas the doppler detectors may not be combined in this manner. Doppler detectors may be combined for data transmission by the use of multiplexing. For each doppler detector handled by multiplexing, it is possible to substitute the number of contact closure systems carried by one pair of lines using telemetering or tone equipment. The ultrasonic detectors had another advantage over the radar detector demonstrated. The electronic chassis was separated from the inert sensing head mounted over the roadway which would permit normal servicing without necessitating the closure of an expressway lane and the switching of a single detector chassis between several sensing heads.

The output voltages of V.O. and V.O.S. computers were expressed in the same numerical value as the measured traffic flow values; that is, 48 volts equals 48 vehicles per minute, or 48 percent occupancy, or 48 mph. Also, the outputs of the meters were all calibrated the same (0-100) and were not affected by control adjustment knobs or range adjustments. These features are all most beneficial when the equipment is to be operated with a data-logging system. It was decided therefore to choose the presence-type detector and its associated computer as the prime measuring tool for the pilot detection system. There was however one major modification in the equipment purchased from that which was demonstrated. Only parameters directly measured are used in the system; therefore, the "on line" computed speed of the V.O.S. was not included in the purchased equipment.

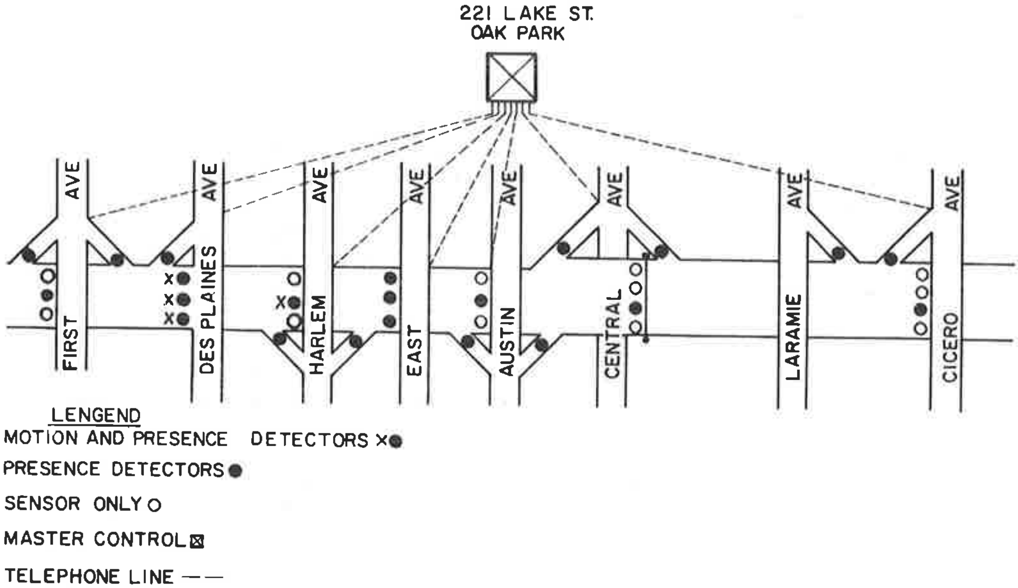


Figure 8. Proposed pilot detection system.

PILOT DETECTION SYSTEM DESIGN

Field Design

All field electronic equipment that was a part of the pilot detection system was installed along the right side of the expressway. Personnel performing routine maintenance, therefore, are not required to cross lanes when driving between sensing stations. Each detector chassis is housed in an individual roadside case; thus, any detector may be moved individually to a new location with a minimum of disturbance to other equipment.

Mainline.—There are seven mainline stations along the expressway where westbound through traffic is sensed for input to the pilot detection system (Fig. 8). Pavement-seeking sonic-type vehicle detectors were selected for this application. These detectors have a high resolution and, because of their pavement seeking feature, operation is not disturbed by the existence of other sonic equipment nearby.

The pavement-seeking sonic detectors consist of a transducer and an electronic chassis. The transducer (Fig. 9) is installed over the roadway and normally requires little or no maintenance. The electronic chassis is housed in a weathertight case on a pedestal located to the right of the paved shoulder for westbound expressway traffic.

The sensor heads (transducers) are mounted on existing structures; 19 are clamped to the flanges of beams at overpasses and 4 are attached to a sign bridge. There is a sensor head over each lane at each of the seven stations.

Ramp Detectors.—In addition to the detectors for through traffic, detectors are also located at each on-ramp and each off-ramp for westbound traffic within the 5-mi section of the pilot detection system. Because of the wide range of ramp traffic vehicle placement, side-fire sonic-type detectors were selected for this application. (Although it is possible for traffic to form two lanes on these ramps, this has never been observed at any of the ramp detector locations.)

The side-fire type of detector consists of a transducer and an electronic chassis. The transducers are installed on existing street light poles at all locations except four. Pedestals for supporting the side-fire detector transducers were installed at the four locations where street light poles are not used (Fig. 10). The electronic chassis for each side-fire detector is located in a roadside cabinet. The cabinet is attached to the same structure as the transducer, except at locations having left-side ramps. The cab-

Figure 9. Mainline detector station.

inets for detectors at left-side ramps are located remotely from the transducer on the right side of the expressway. At each of the eleven locations, the ramp traffic may be observed at the roadside case location.

Special Equipment.—In addition to the mainline and ramp equipment already mentioned, the following field equipment is also included.

Motion Detectors.—Direct speed-sensing capabilities are included in the pilot detection system at four locations. Sonic vehicle detectors employing a doppler principle provide the means for this feature. Each motion detector requires a transducer over the lane where speed is to be sensed. The transducer is connected to an electronic chassis located in a weathertight roadside case. The case is mounted on a pedestal installed to the right of the paved shoulder for westbound traffic.

Pavement Condition Detector.— A surface-mounted moisture and temperature sensor is included as part of the pilot detection system. The unit is installed in the right lane for westbound expressway traffic at the Des Plaines station. The sensor is connected to an electronic chassis which is located in a pedestal-mounted roadside case.

The pavement detector provides system capability for sensing wet or snow covered roadway and, at the same time, indicates when freezing temperature exists.

Chassis Switch.—All lanes for westbound traffic are sensed concurrently at the East Avenue detector station. Sensing at the six other mainline stations of the pilot detection system uses a sampling technique whereby only one lane is sensed at a time.

As previously mentioned, transducers are installed over each lane at each mainline station. The design of the East Avenue station requires that three electronic chassis be provided, one for each transducer. Only one electronic chassis, however, is provided at each of the six other stations, and by means of a remotely-operated switch the chassis may be connected to any one of the lane transducers provided at their assigned station.

Interconnect.—The interconnect system may be divided into two sections, that owned by the State of Illinois and that leased from the telephone company.

The State-owned interconnect is installed along the expressway connecting the ramp detectors at each station to the other equipment at the same station. The cabling consists of a service pair plus two pair of voice grade cables directly buried along the shoulder. The service cable usually is extended beyond the expressway right-of-way

Figure 10. Side-fire detector.

to the nearest service location where it is connected to 117 volts. The leased lines, depending on their use, are either voice or 0- to 15-cycle grade.

Telephone Lines (Data and Voice).— Low-grade (0- to 15-cycle) lines are used for all ramp detectors, the ice-rain detector, two of the East Avenue mainline detectors, and one detector at Des Plaines Avenue. All remaining interconnect lines are voice grade. Although the mainline detectors do not require voice grade line for the transmission of detector output, the voice grade lines are required for use with the special telephone equipment at the same locations. Whenever the telephone circuit feature of each mainline station is placed in operation, the mainline interconnect line is then used for voice communication, either between stations or between a station and the office, or both. Data are interrupted during voice interconnect.

Voice grade interconnect lines are also required for transmitting the doppler frequency output of the motion detectors located on the expressway to the V.S. computers located in the office.

Tone Equipment.— Special tone equipment is installed at the Des Plaines Station. The tone equipment provides system capability for transmitting the outputs of five separate detectors simultaneously over one voice grade telephone interconnect line. The unit is to be used during an extensive study for determining how accurately traffic data may be transmitted by tone equipment. If satisfactory results are found, the extensions of the pilot detection system will consider additional tone equipment.

Office Equipment Design

The office equipment for the pilot detection system is installed on the second floor at 221 Lake Street, Oak Park, Ill. The electronic components of the office equipment are mounted in a ten-bay relay rack (Fig. 11). Included in the racks are all averaging computers, level monitors, power supplies, printer, plotter, etc. Mounted above the racks is a 3- by 16-ft map panel.

Computers.—The design of the pilot detection system is such that practically all computing is performed by additional high-speed digital computers. Running averages, however, are computed on line by the system, and are obtained from basic analog circuits. There are two types of analog computing units in the system, volume-speed computers, and volume-occupancy computers.

The volume-speed computers obtain their input from the motion detectors. Individual speed on a per-car-per-lane basis is available from the output of this computer, as well as running average lane volume in vehicles per lane per minute and running average lane speeds in miles per hour. Four volume-speed computers are included in the system.

The volume-occupancy computers receive input from the presence-type sensors. Two outputs are provided from the volume-occupancy computers, a running average

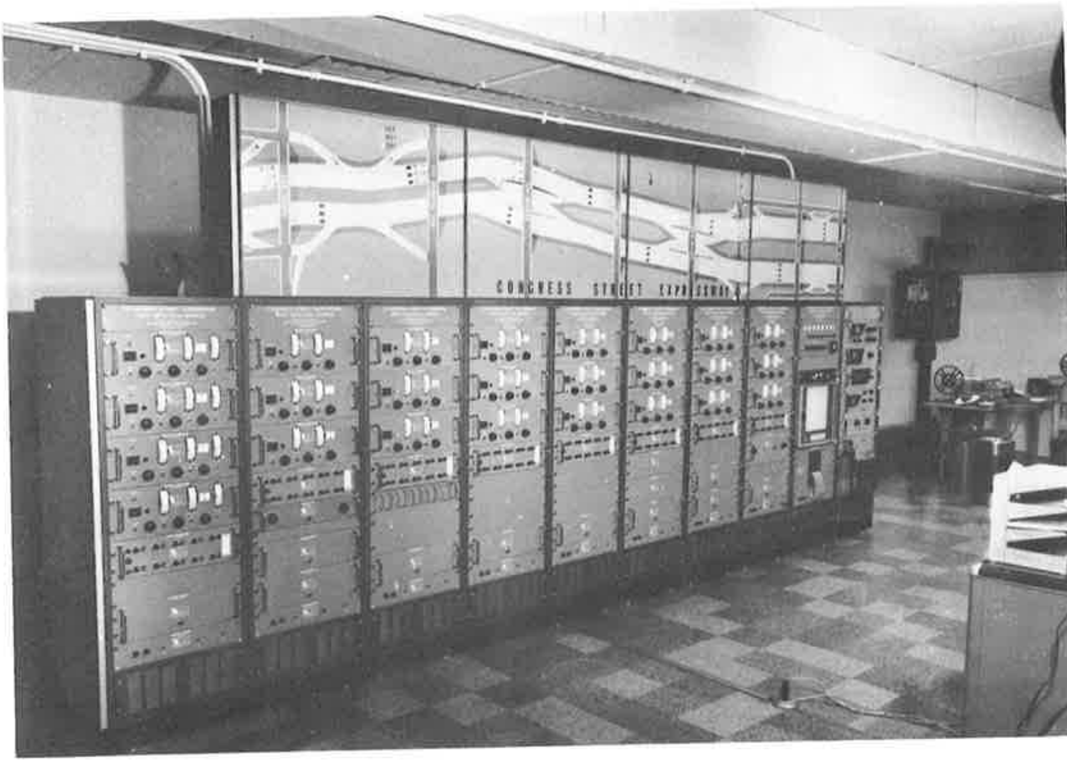


Figure 11. Ten racks of office equipment.

volume in vehicles per lane per minute and a running average occupancy in percentage of time a vehicle is present in a lane to total time. There are 21 volume-occupancy computers in the system.

Qualitative Output.—The outputs of the averaging computers may be fed to several components of the system, one of which is a level monitor. A level monitor might also be called a "comparator," in that the level monitor compares the output of the computer to the setting of one of its controls. Whenever the output of the computer is less than the setting of the level monitor, a contact in the level monitor will remain open; however, if the computer output equals or exceeds the setting of the level monitor, the contact will close. The level monitor may be used to separate data into class intervals, or to operate control devices or displays. Eighty level monitor channels are provided in the pilot detection system.

The five-mile section of the Congress Street Expressway, including the locations for the sensors for the pilot detection system, is displayed on a map panel. The map panel is mounted above the relay racks in the project's office. Indicator lamps on the map panel at the approximate location of each detector display the level of operation of the expressway for that location. Level monitor sections connected to computers are set to control the indications, causing a display of green, yellow, red, or flashing red for each detector location.

Data Logging.—The pilot detection system was designed principally for use in collecting traffic flow data. To this end, three different recording devices are provided: an X-Y recorder, a printed tape recorder, and a punched tape recorder (Fig. 12).

X-Y Recorder.—Any two analog values or any one analog value and time may be plotted on a 10 by 10 paper chart provided by the X-Y recorder. The analog value may be either an output of one of the computers, or it may be the difference between two computer outputs. The circuitry is such that other recorders may be operated concurrently with the X-Y, using the same analog voltages, without affecting the results.

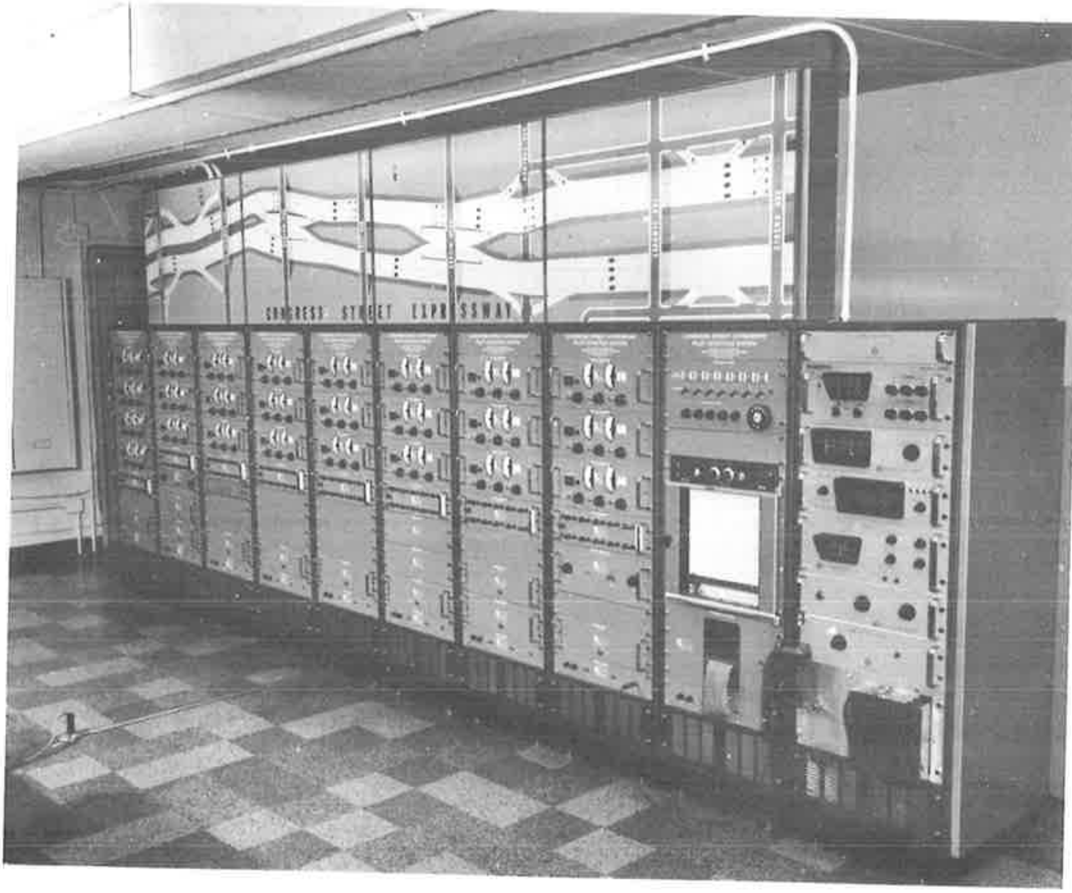


Figure 12. Racks showing data-logging equipment and X-Y plotter.

Printed Tape.—The output from as many as three detectors may be fed to the printer-counter at one time. Means are also provided by the printer-counter so that percentage occupancy may be recorded from one detector. A clock in the unit provides means for printing out accumulated totals for one, three, or six minutes. Print-out may also be initiated from the digital clock of the data-logging system, or manually.

Punched Tape.—Traffic flow data sensed by the pilot detection system may be recorded on punched paper tape by means of the data-logging system. The tapes are coded for input to a digital computer. The system consists of a digital clock, a scanner, a voltage-to-digital converter, a serializer, and a perforator. The clock provides time digits for recording on the tape as well as punch-out commands. The data-logging system may be operated in any of three modes.

During mode 1 operation, the clock will provide "repeat cycle" commands for initiating scanning cycles. These in turn will start the scanner through one scan with each command. The scanner will, during a scan, connect each output, one at a time, to the voltage-to-digital converter. The output of the voltage-to-digital converter will be fed through the serializer and punched out on the paper tape by means of the perforator. The perforator will punch out as many as five computer outputs per second.

During mode 2, the data logger may be set to record individual speed (or other individual input data) at one detector location. When operating in mode 2, the resulting punched tape will contain time in seconds and tenths of seconds, as well as, the individual speed for each vehicle as it is detected on the expressway. Thus, when using mode 2, speed distribution and time headway may be recorded.

Mode 3 is similar to mode 1 except that the scanner cycles continuously, rather than at fixed time intervals.

Flexowriter.—A Flexowriter is provided as part of the pilot detection system for printing out tapes made by the data logger, or for preparing tape for analysis on a digital computer.

INITIAL STUDIES

The installation of the pilot detection system began in May 1962, and detectors and associated computers for the first two stations (Des Plaines and First Avenue) went into operation during the latter part of June. During the remainder of the summer the other detectors and computers were placed in operation, as were the various data output units (printer-counter, X-Y plotter, map display, and punch tape). On September 12, 1962, the entire pilot detection system was officially turned on.

As individual components of the system became operational, they were adjusted and calibrated in preparation for the initial operational studies. Some of the results of these adjustments and initial studies are described next.

Traffic Analyzer Study

The Bureau of Public Roads' traffic analyzer was used to evaluate and calibrate the four motion detectors of the pilot detection system. At each of the four detector locations, a pair of hoses of the traffic analyzer was installed so that the motion detectors picked up the speed of individual vehicles within the traffic analyzer's 30-ft speed trap. The phone circuit of the pilot detection system was employed to inform observers of both sets of equipment the instant that an individual vehicle entered the measuring zone, and also was used to convey the individual speed readings of the traffic analyzer to the project office. In this manner, the comparison of individual vehicle speeds could be made and permitted the analyses of the speed data to be carried out concurrently with the data collection.

The tests were conducted during early morning low-volume high-speed traffic conditions so that individual vehicles could be recognized by both sets of equipment. Test vehicles were driven at low speeds to compare speed measurements in the low speed range.

A summary of the study results are given in Table 1. The final adjustments for the four motion detectors were 0.0, 1.8, 1.6, and 1.0 mph for Harlem - lane 2, Des Plaines - lane 3, Des Plaines - lane 2, and Des Plaines - lane 1, respectively. At low speeds, the detector speeds are higher than the traffic analyzer speeds (1 to 2 mph), whereas at high speeds the detectors' speeds are within 0.4 mph of the traffic analyzer speeds. The comparison between the speed detectors and traffic analyzer before and after calibration is shown in Figure 13.

Initial Studies with On-Line X-Y Plotter

The pilot detection system includes an X-Y plotter which permits the on-line plotting of one variable (volume, speed or occupancy) vs time or one variable vs another variable. A master panel board permits the use of any measured variable at any location to be plotted against any other measured variable at any location. Sample X-Y plots are shown in Figures 14, 15, and 16.

Initial Studies with Printer-Counter

Initial uses of the printer-counter included the evaluation of the 38 volume detectors and the recording of lane volumes for preliminary determination of volume variations and lane volume distributions.

Evaluation of Volume Detectors.—In testing each volume detector, the count obtained from the detector, the occupancy obtained from the detector, the manual lane count, and the time were printed on the printer-counter every three minutes until 1,000 counts were received. Counts were taken during moderate to heavy traffic flow. If the difference between the detector count and the manual count exceeded 4 percent, the per-

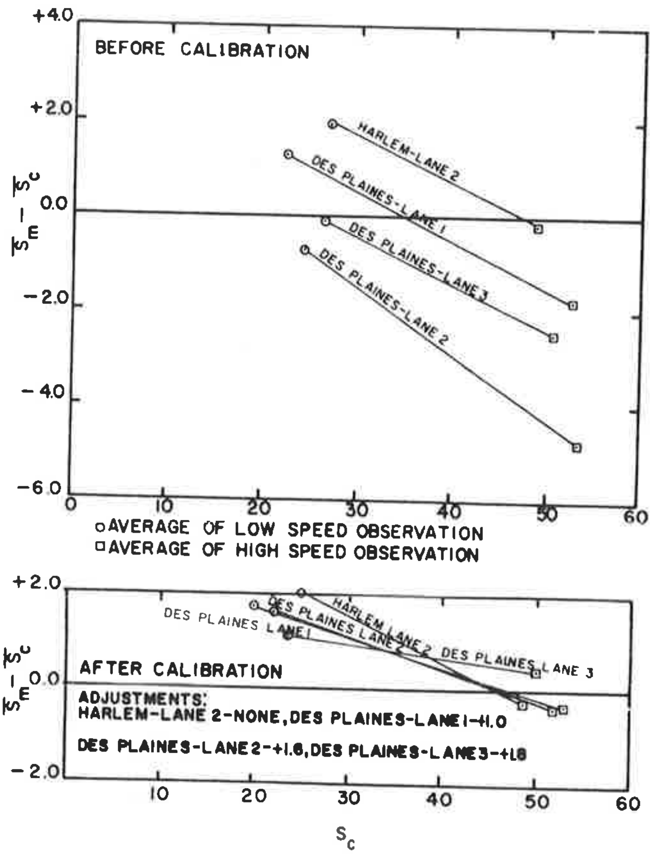


Figure 13. Calibration of speed detectors with traffic analyzer (Dec. 1962).

TABLE 1

SUMMARY OF STUDY RESULTS

Location	Lane[1]	Calibration[2]	Result Average: Low-Speed: Detector Speed	Low-Speed: BPR Speed	Low-Speed: Difference[3]	Low-Speed: Sample Size[4]	High-Speed: Detector Speed	High-Speed: BPR Speed	High-Speed: Difference	High-Speed: Sample Size[5]	Percent of Individual Speeds Within Range[6]: Low-Speed: ± 2 mph	Low-Speed: ± 5 mph	High-Speed: ± 2 mph	High-Speed: ± 5 mph
Harlem	2	None	28.6	26.6	+2.0	32	48.5	48.7	-0.2	100	97	100	46	94
Des Plaines	3	None	26.7	26.8	-0.1	33	48.5	51.0	-2.5	100	94	100	65	96
		+1.8	25.4	24.3	+1.1	37	50.5	50.1	+0.4	100	100	100	76	99
	2	None	23.7	24.4	-0.7	32	48.5	53.3	-4.8	100	88	100	27	78
		+3.0	25.6	24.8	+0.8	6	52.4	51.9	+0.5	100	50	100	35	79
		+3.0	26.5	24.1	+2.4	30	55.5	54.9	+0.8	100	83	97	40	79
		—[7]	25.4	23.8	+1.6	31	51.8	52.2	-0.4	106	97	100	46	89
	1	None	23.9	22.6	+1.3	30	50.4	52.2	-1.8	100	100	100	40	79
		+1.0	23.2	21.5	+1.7	31	52.0	52.4	-0.4	100	30	100	37	86

[1] Lanes 1, 2, and 3 are median, middle, and shoulder lane, respectively.
[2] None before calibration; + x.x = amount of calibration; underscore = final setting.
[3] + = detector speed BPR speed; - = detector speed BPR speed.
[4] Four test vehicles employed to obtain low speeds.
[5] Individual vehicles in traffic stream observed.
[6] For example, at Harlem lane 2, individual detector speed of 94 percent (94 out of 100 vehicles) was within ± 5 mph of the BPR individual speeds.
[7] Original adjustment + 3.0 and second adjustment -1.4, for net adjustment of + 1.6.

formance was not acceptable. The three types of volume detectors used in the pilot detection system are 11 side-fire detectors (used on ramps only), 4 motion detectors, and 23 presence detectors. Using the manual count as the standard, the performance

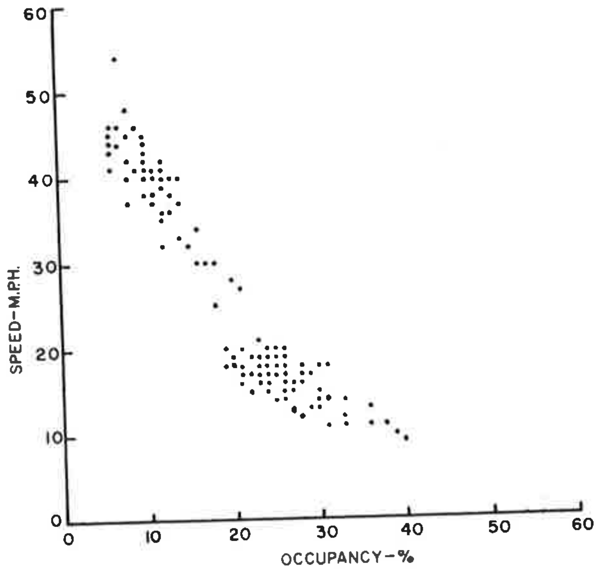


Figure 14. Off-line speed occupancy scatter diagram.

of the three types of detectors was evaluated, and a summary of the results is given in Table 2. The side-fire detectors ranged from -2.5 to 1.7 percent difference from the manual count, with five of the detectors undercounting and six of the detectors overcounting (average error of -0.3 percent). The motion detectors ranged from -1.7 to -0.5 percent difference from the manual count, with all four detectors undercounting (average error of -1.3 percent). The presence detectors ranged from -3.9 to 3.6 percent difference from the manual count with nineteen of the detectors undercounting and four of the detectors overcounting (average error of -1.7 percent).

Volume Variations and Lane Volume Distributions.—The printer-counter was used to record hourly volumes in each of the three lanes at East Avenue, which is located in the center portion of the study section. These measurements were recorded 24 hr per day from Thursday, October 4, through Thursday, October 24, 1962. The purpose of this study was the preliminary determination of daily and hourly volume variations and the distribution of traffic volumes between lanes.

The average daily volume and the average weekday volume during the three-week study were 58,200 and 61,000 vehicles, respectively. The average daily factors and the average weekday factors are given in Table 3. The 24-hr average volumes are also given.

The weekday volumes increase as the week progresses (Monday to Tuesday to Wednesday, etc.) with Friday having the highest 24-hr volume. The hourly variations for the fifteen weekdays from October 4 to 24, 1962, are shown in Figure 17.

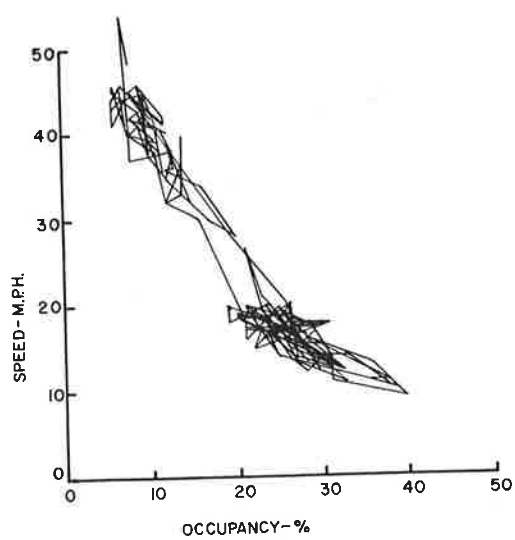


Figure 15. Off-line speed occupancy continuous diagram.

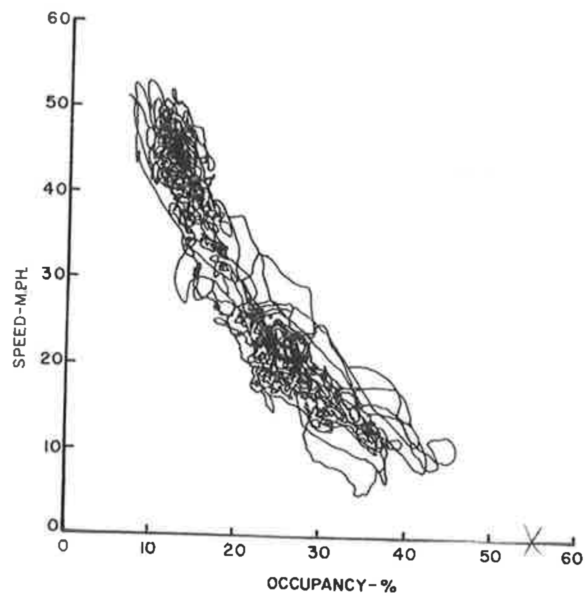


Figure 16. On-line speed occupancy continuous diagram.

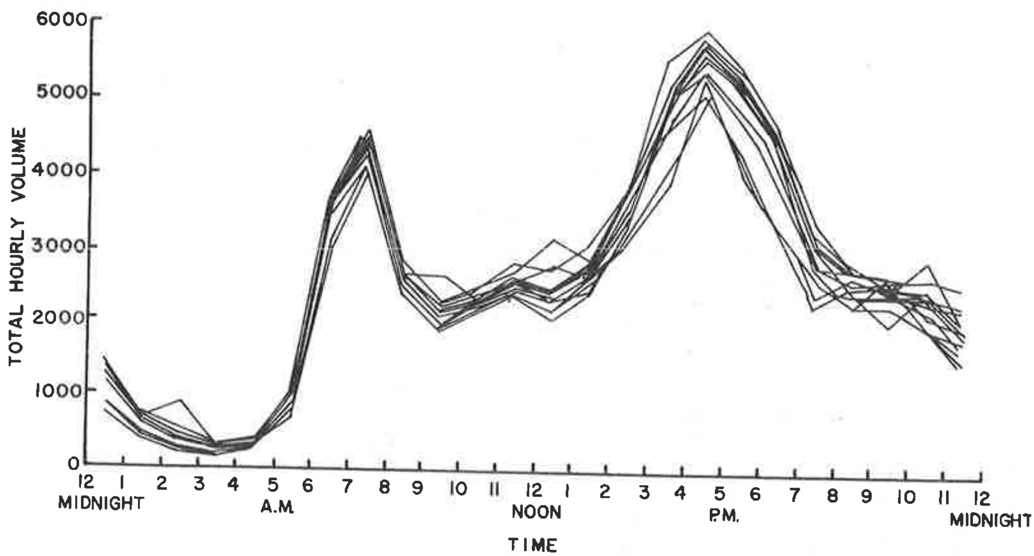


Figure 17. Hourly volume variations on westbound Congress Street Expressway (East Avenue, Oct. 4 to 24, 1962.

Figure 17 shows the hourly variations for the fifteen weekdays are very similar throughout the 24-hr period. The morning peak hour (7 to 8 AM) varies from 3,900 to 4,600 vehicles and the afternoon peak hour (4 to 5 PM) varies from 5,000 to 6,000 vehicles. The peak-hour factors (the ratio of the 4 to 5 PM hour volume to the 24-hr volume expressed as a percentage) for each of the fifteen weekdays are given in Table 4.

The distribution of hourly volumes between the median, middle, and shoulder lanes is shown in Figure 18. Lane 1 (the median lane) carried less traffic than lane 2 or 3 during light volume conditions (total volume of 0 to 1,000 vehicles per hour). As the total volume increases (3,000 to 4,000 vehicles per hour), the portion of traffic in lane

TABLE 2

VOLUME MEASUREMENT COMPARISON OF SIDE-FIRE, MOTION AND PRESENCE DETECTORS TO MANUAL COUNT

Location			Volume Measurement (%)		
Station	Avenue	Lane or Ramp	Side-Fire Detector	Motion Detector	Presence Detector
1	Cicero	Lane 1	—	—	-1.5[1]
		Lane 2	—	—	-1.7
		Lane 3	—	—	-1.8
		Lane 4	—	—	+0.7
		Entrance ramp	+0.9	—	—
		Exit ramp	-0.9	—	—
2	Central	Lane 1	—	—	-1.7
		Lane 2	—	—	-3.2
		Lane 3	—	—	-2.9
		Lane 4	—	—	-3.9
		Entrance ramp	-2.5	—	—
		Exit ramp	+0.1	—	—
3	Austin	Lane 1	—	—	-0.3
		Lane 2	—	—	-1.0
		Lane 3	—	—	+1.4
		Entrance ramp	+1.7	—	—
		Exit ramp	+0.3	—	—
4	East	Lane 1	—	—	-0.9
		Lane 2	—	—	-1.6
		Lane 3	—	—	-1.7
5	Harlem	Lane 1	—	—	+3.6
		Lane 2	—	-1.7	-2.0
		Lane 3	—	—	+0.8
		Entrance ramp	+0.4	—	—
6	Des Plaines	Lane 1	—	-1.5	-1.3
		Lane 2	—	-0.5	-3.6
		Lane 3	—	-1.4	-3.7
		Entrance ramp	-1.8	—	—
7	First	Lane 1	—	—	-1.7
		Lane 2	—	—	-3.6
		Lane 3	—	—	-0.8
		Entrance ramp	+0.2	—	—
		Exit ramp	-0.4	—	—
	Range		-2.5 to +1.7	-1.7 to -0.5	-3.9 to +3.6
	Undercounts (-)		5	4	19
	Overcounts (+)		6	0	4
	Avg. error		-0.3	-1.3	-1.7

[1] Figures obtained by $\% = \left(\frac{V_{detector} - V_{manual}}{V_{manual}} \right) 100.$

1 increases to 40 percent and equals the amount of traffic in lane 2. At the highest observed hourly volumes (5,000 to 6,000 vehicles), the volumes of lanes 1 and 2 are equal, and each carried 35 to 40 percent of the total volume. Except at total hourly volumes less than 1,000 vehicles per hour, lane 3 (shoulder lane) carries the smallest portion of the total volume and this portion is between 20 and 28 percent of the total volume.

TABLE 3

AVERAGE DAILY AND WEEKDAY VOLUMES

Day of Week	Average Daily Factors[1]	Average Weekday Factors[1]	Daily Volume
Sunday	0.81	—	46,900
Monday	1.01	0.95	58,500
Tuesday	1.02	0.96	59,300
Wednesday	1.06	1.00	61,600
Thursday	1.09	1.03	63,700
Friday	1.11	1.05	64,800
Saturday	0.91	—	53,100

[1] $\frac{\text{Day of week vol.}}{\text{Average daily vol.}}$.

[2] $\frac{\text{Day of week vol.}}{\text{Average weekday vol.}}$.

TABLE 4

PEAK-HOUR FACTORS

Day	Peak-Hour Factor (%)[1]			
	Week One	Week Two	Week Three	Average
Thursday	8.5	9.0	8.9	8.8
Friday	8.9	8.6	8.9	8.8
Monday	9.8	9.5	9.1	9.5
Tuesday	9.0	9.4	9.2	9.2
Wednesday	9.0	9.4	9.2	9.2
Average	9.0	9.2	9.1	9.1

[1] Figures obtained by:

Peak-hour factor (%) = $\frac{\text{4 to 5 PM hr vol.}}{\text{24 hr vol.}}$.

Peak-hour factors vary from 8.5 to 9.5 percent with overall average peak-hour factor of 9.1 percent.

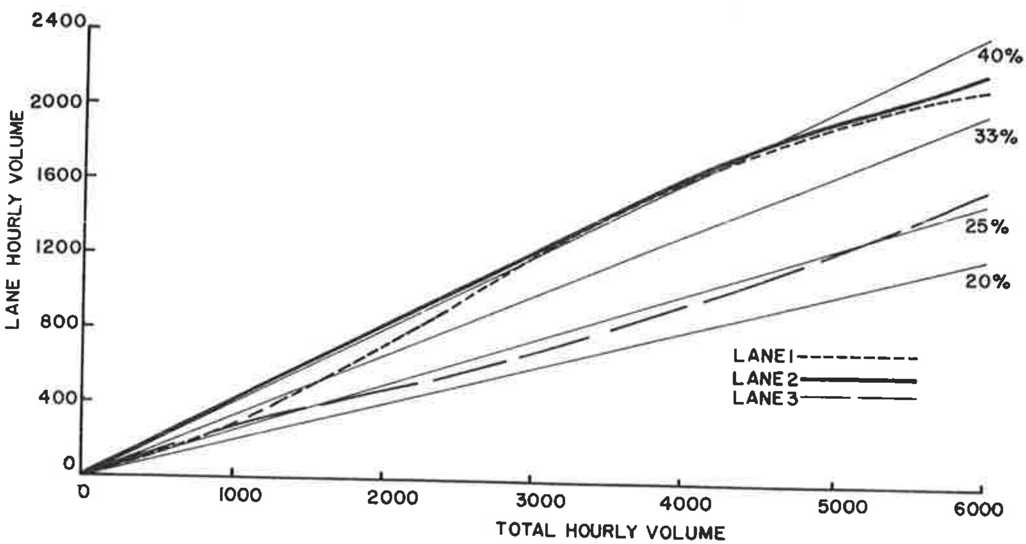


Figure 18. Lane distribution on westbound Congress Street Expressway (East Avenue).

Initial Studies with Map Display

At each mainline station of the five-mile study section, a light indicator is displayed on the map panel. The color of the light is selected based on the level occupancy measured at the mainline station. The four conditions denoted are given in Table 5.

During the afternoon peak traffic period (3 to 7 PM) the mainline light indicators were recorded each minute on Wednesday, October 10, 1962. Figure 19 shows how the map display presented the various levels of operation during a typical weekday afternoon peak period.

Free flow (zone 1) was maintained at the output station (First Avenue) during the entire afternoon peak period. Congestion, identified by zones 3 and 4, began at 4:23 PM

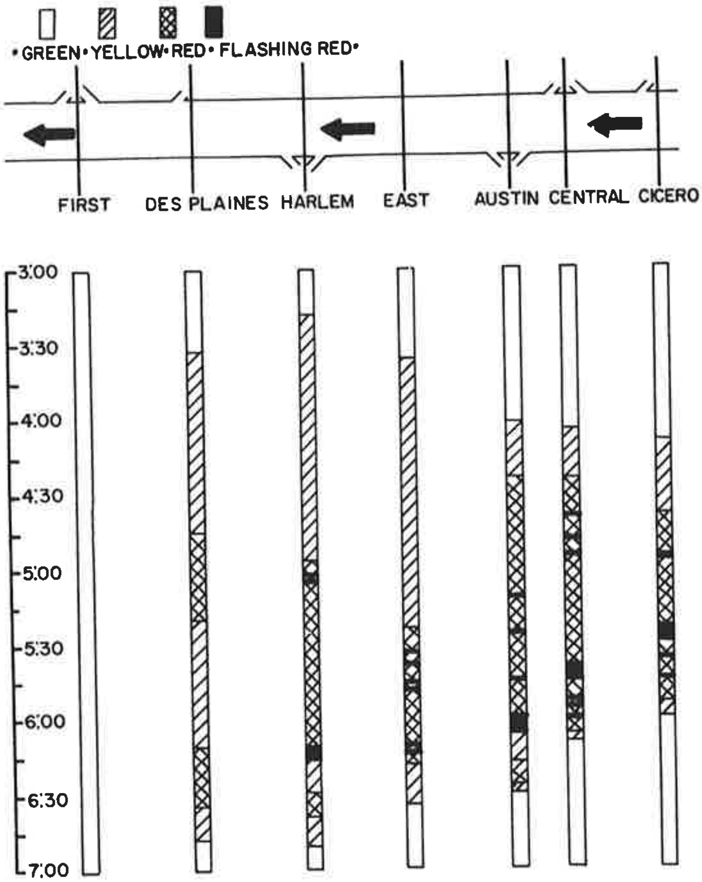


Figure 19. Map display indications during afternoon peak period (Oct. 10, 1962).

at Austin and at 4:42 PM at Des Plaines. By 5:10 PM congestion was evident from Des Plaines upstream through the study section. By 6:30 PM traffic began to move more freely, and by 6:50 PM free flow existed throughout the study section.

Initial Studies with Punch Tape Output

During a comprehensive three-week study, some 84 measurements from the pilot detection system were punched on paper tape for each minute for three consecutive weeks. The paper tape can be directly fed into a G-15 Bendix computer for analyses and a number of studies are now being undertaken in this fashion. In addition, the paper tape can be converted to a printed tape by the use of a Flexowriter, and a sample portion of the tape for four consecutive scans is given in Table 6.

TABLE 5

LIGHT COLOR SELECTION

Zone	Indicator	Occupancy Level (%)	Freeway Conditions[1]
1	Green	0-15	Volume demand speed 40 mph
2	Yellow	15-25	Volume = demand speed 30-40 mph
3	Red	25-40	Demand volume speed 10-30 mph
4	Flashing red	40	Demand volume speed 10 mph

[1]Approximate.

TABLE 6

PRINTED RESULTS OF PUNCHED TAPE SAMPLE OUTPUT

Channel	Description	Traffic Data for Minute Ending			
		4:39 PM	4:40 PM	4:41 PM	4:42 PM
001	Temperature	2	2	2	2
002	Degree of precipitation	0	0	0	0
003	Sky cover condition	0	0	0	0
004	Persons on duty	8	8	8	8
005	Special traffic events	0	0	0	0
006	Pavement condition	1	1	1	1
007	Des Plaines Lane 1 - volume	30	32	34	32
008	Des Plaines Lane 1 - speed	40	37	22	23
009	Des Plaines Lane 2 - volume	34	33	34	34
010	Des Plaines Lane 2 - speed	38	35	29	24
011	Des Plaines Lane 3 - volume	21	25	29	28
012	Des Plaines Lane 3 - speed	39	37	31	25
013					
014					
075	Des Plaines Lane 2 - volume	34	33	33	33
076	Des Plaines Lane 2 - occupancy	18	19	21	26
077	Des Plaines On-ramp - volume	17	14	14	14
078	Des Plaines On-ramp - occupancy	10	8	10	9
084					

The first six channels are used to record non-traffic measurements, and the data entries of 2, 0, 0, 8, 0, and 1, respectively, indicate temperatures between 70-85 F, no precipitation, clear skies, persons on duty, no special traffic events, and pavement dry and above freezing. Channels 007 through 084 are used to record traffic measurements at some 25 lane locations. The opportunity of analyzing such traffic data is almost unlimited, and Table 6 gives some of the initial traffic studies that are being made from the punched tape output:

1. Interrelationships between volume, occupancy, and speed.
2. Comparison of measured speed and speed calculated from volume and occupancy.
3. Comparison of measured occupancy and density calculated from volume and speed.
4. Comparison of lane traffic characteristics.
5. Comparison of traffic characteristics between mainline stations.
6. Changes in traffic characteristics just before congestion.
7. Combination of shoulder lane volume and ramp volume resulting in maximum flow and satisfactory operation.
8. Measurement of the effect of congestion on traffic flow and travel time.

In summary, the pilot detection system is providing the expressway surveillance project staff with a comprehensive library of measurements over an expressway section and for periods of time which permit microscopic and macroscopic investigations both qualitative and quantitative, and the data-logging subsystem is recording the measurements in a manner that makes full use of data-processing equipment with minimum of time and without loss of accuracy.

Lodge Freeway Traffic Surveillance And Control Project

Development and Evaluation

FRANK DeROSE, JR., Project Engineer, Freeway Surveillance Project, Michigan State Highway Department

This paper analyzes and evaluates the important characteristics and accessories of a closed-circuit television system for viewing urban freeway traffic and aiding in traffic control. The closed-circuit television system consisted of cameras, monitors, transmission equipment, and accessories. The paper also describes some typical research studies using the television system.

•THE John C. Lodge Freeway Traffic Surveillance and Control Research Project in cooperation with the U.S. Bureau of Public Roads is being conducted jointly by the Michigan State Highway Department, the City of Detroit Department of Streets and Traffic, and the Wayne County Road Commission. The project was initiated in July 1960. It is being conducted on the John C. Lodge Freeway between the Edsel Ford Freeway and the Davison Freeway. The study section is 3.2 mi long and includes portions of three- and four-lane freeway, as well as 9 off-ramps and 9 on-ramps (Fig. 1).

The project was programed over a 2-yr period and has provided an opportunity to conduct research on various aspects of driver and vehicle behavior on a heavily-traveled freeway. In addition, it has provided an excellent laboratory for the design, development, and evaluation of new and specialized electronic equipment for use in the study and control of freeway traffic characteristics. A great percentage of the effort and work on the project has been concentrated on designing and obtaining this instrumentation. During this period, equipment has been installed and its operating capabilities appraised; only in recent months has all the equipment been available for application to a concerted research effort.

The major objectives of the project are two. The first is to apply the latest developments in electronic and other related technological equipment to increase operational efficiency on the freeway. The equipment includes a closed-circuit television network and a traffic control system of lane signals, speed signals, and ramp closure signals. The second objective is to evaluate the effectiveness of this equipment in obtaining increased efficiency in freeway operation, as well as to conduct research on freeway traffic characteristics. The latter is directed toward the determination of interrelationships of traffic flow characteristics, new concepts on freeway traffic flow, and the study of driver behavior and its effect on freeway operation efficiency. For this purpose the General Railway Signal Company has loaned the project sensing and computer equipment for traffic data collection.

PROJECT INSTRUMENTATION

The instrumentation used is the latest and most sophisticated of its kind ever assembled for research activity as well as for traffic control. This affords an unequaled laboratory for research in freeway traffic study and control.

Paper sponsored by Committee on Freeway Operations.

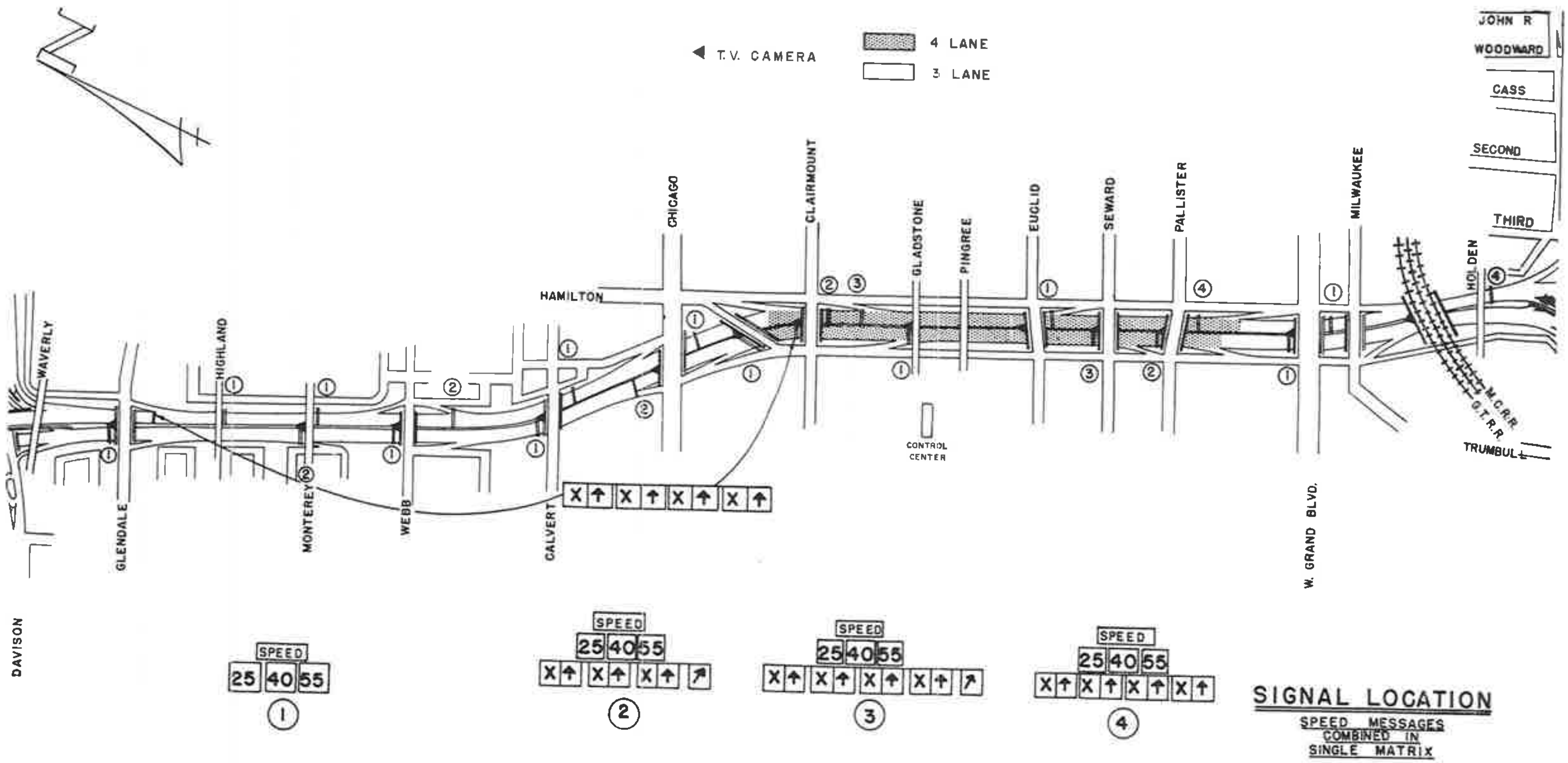


Figure 1. Signal and TV camera location, John C. Lodge Freeway, Detroit, Mich.

The instrumentation and equipment are grouped into three basic categories: television surveillance system, traffic control system, and traffic information collection equipment.

Television Surveillance System

On the project, there are 14 television cameras spaced approximately ¼-mi apart, covering a continuous 3.2-mi area of the freeway (Fig. 1). This television system provided the principal type of surveillance. The television reception is transmitted to a control center located about midway in the study section. At the center, 14 monitors receive the video transmission from the cameras. Remote control is maintained here of all the available functions at all cameras, including changing a camera's normal lens to a telephoto lens, focusing, panning and tilting (that is, moving the camera right or left or up or down), and controlling the iris on each camera to regulate the amount of light received by the vidicon tube. In addition, the system provides for the automatic sequencing of the picture on the 14 monitors; with the spare monitor available, sequencing operation can be viewed independent of the 14 regular monitors.

Television surveillance has already revealed how very minor disturbances in the freeway traffic stream create congestion and may cause unsafe conditions. Surveillance and detection can be done in a matter of seconds. After 20 months of operation, there is no doubt that the system serves very efficiently for detection and, subsequently, has aided greatly in the traffic control corrective measures that have been made. The visual observation of the traffic stream and, in particular, traffic situations such as accidents, congestion, and vehicle breakdowns, has been of tremendous help in aiding the operator to detect the situation, determine its scope and extent, make the necessary corrective action, and immediately evaluate the result of this corrective action.

Experience so far has led to the conclusion that it would be extremely difficult to operate an efficient traffic control system without the type of viewing provided here.

Traffic Control System

Lane Control Signals. —The traffic control system consists of lane signals and variable speed signs on the freeway, and ramp closure signs for control of the on-ramps. Lane signals and variable speed signs were installed during the early months of 1962, and operation of them began on May 7, following a 30-day shakedown period for operating errors. The lane signals use the red X and green arrows which are the new national standards for signals of this type (Fig. 1). The red X means the driver must leave the lane, as soon as it is safe to do so, and move over to a lane displaying a green arrow, either a through lane or an exit ramp lane at the location where the signal span is installed. The green arrow indicates that the lane is open to traffic but does not mean that the driver has a route guaranteeing absence of traffic stoppages. The red X is not employed unless the lane is closed for maintenance or an emergency. The lane control signals are installed at 11 locations in the study section—6 for the northbound and 5 for the southbound direction.

Variable Speed Control. —A variable speed sign is used in conjunction with the lane signals. It displays messages in 5-mph increments over a range of 20 to 60 mph. Speeds are determined through the sensing equipment from information that has been automatically analyzed by computers in the control center. Signs have been installed at 21 locations; in some instances, with a lane signal span, and in others, by itself. There are 11 for the northbound and 10 for the southbound direction.

Ramp Control. —In addition to the lane signals and variable speed signs, ramp signals are being installed on each on-ramp in the study section. There are 9 such locations—4 northbound and 5 southbound. These signals enable the operator to close a ramp if congestion or an incident has occurred on the freeway near an on-ramp, diverting traffic along an alternate route until it can conveniently enter the freeway. The ramp signal's legend is "Don't Enter." It is a blank-out sign with a legend plate with the word "Ramp" attached to the bottom. The control center operator is able to close ramps when necessary and provide better control of entering traffic, thereby increasing not only the efficiency of the control system but also the capacity and operation of the freeway. There has been no opportunity to evaluate these signals individually or the control system with these signals in operation.

Supervisory Control. —The nature of the freeway lane signals, variable speed signs, and ramp control requires a remote control facility. The supervisory control equipment, located at the TV control center, is operated by personnel observing the freeway traffic. A console contains the controls to activate any signal or speed sign. On detection of an incident on the freeway the control operator selects the function needed to alleviate whatever situation has occurred.

The operator is provided with a confirmation panel which shows on a schematic of the study section the location of the signals and signs. The confirmation panel through the supervisory control circuitry informs the operator that the function selected has been properly sent and confirms that the message has been received and is not in error. Because of the critical nature of any action that causes a change in traffic flow, it is obvious that the control system must possess a means of positive confirmation. This control system circuitry will automatically tell an operator immediately whether there is any malfunction in the system. This equipment permits the selection of complex functions which can be carried out with complete reliability because of the fail-safe features.

Future Equipment Requirements. —An evaluation during recent months of operation has revealed that certain additions and revisions are necessary if the complete potential of the control system is to be realized. The system cannot provide optimum control of freeway traffic unless these changes are incorporated as part of the total system. As this system was the pioneer project of its kind, it is natural that changes would follow the initial operational period. The following are the proposed changes and additions which will satisfy the requirements for properly controlling traffic in the study section:

1. Additional Lane Signals and Speed Signs. When the system was first designed, the present installation of lane signals and speed signs was determined to be the absolute minimum. Project personnel felt that additional signals and signs might have to be installed, but due to financial limitations and the desire to keep costs at a minimum, the present equipment was approved.

However, shortly after beginning operation, it was determined that the distance between adjacent signal spans in two locations was too long for efficient control of traffic. Therefore, two additional spans of lane signals and speed signs are required at Chicago Boulevard for northbound traffic and Webb for southbound.

2. Individual Speed Sign Control. The present system of speed control was designed to gang or zone the speed signals in twos and threes. That is, in some instances one control activates more than one signal simultaneously. Early experience indicated that it would often be desirable to regulate traffic by speed and that a different speed should be displayed at adjacent signals. Therefore, to provide greater flexibility, thus increasing efficiency, it was decided that they should be individually controlled. This will be done as soon as possible.

3. Speed and Presence Detection Equipment and Display. To operate the control system effectively, complete information on speed, occupancy, and volume at many locations must be available. Presently, the only available traffic data that assist in detecting any change in traffic flow and indicate that congestion is eminent are provided from two locations where speed, occupancy, and volume sensors are placed over each lane in both directions. However, such information from these locations may not apply to other areas in the study section limiting the effectiveness of the control.

It is thus proposed that speed and presence detectors be placed equidistantly along the study section to provide the operator with complete information on traffic flow at many points, thereby increasing his knowledge of the existing character of traffic flow and providing greater assistance for judging what control action is required.

Traffic Information Collection Instrumentation

The project has available a laboratory of electronic instrumentation, the latest of its kind, which provides the means of obtaining traffic information. Ultrasonic sensors are used for vehicle detection, the impulses being transmitted to analog computers located at the control center. Here, the information can be read directly from meters or plotted on an eight-pen recorder for later tabulation and analysis. The equipment is capable of providing lane speeds, lane occupancy, lane minute volumes, freeway occupancy, freeway volumes, and freeway average speeds. In addition, it can provide total vehicle counts and distinguish between passenger and commercial vehicles.

The capabilities of this instrumentation are unsurpassed anywhere in the United States, yet it is provided without cost to the project. To purchase all this equipment would cost about $150,000. The capability of the system dictates that the fullest advantage be taken of this opportunity to study freeway traffic characteristics. The large quantity of traffic information requires the application of computers to its analysis and handling.

PROJECT RESEARCH ACTIVITIES

Television Surveillance for Freeway Traffic Observation and Research

The television system provides an excellent opportunity to conduct research into freeway traffic, as well as to employ television surveillance for traffic control. It also has provided the opportunity for extensive use as a research tool in the observation, assimilation, and collection of research information. The system can instantaneously transfer information to an observer who can view a large area of the freeway, follow traffic, and examine details by remote control functions. The unique nature of the application of closed-circuit television to freeway surveillance requires that a complete evaluation be performed on all aspects and features of the television system in anticipation that the system will become a permanent installation for each standard or that similar installations will be undertaken elsewhere.

Technical Evaluation.—A comprehensive evaluation has been conducted to provide an objective appraisal of the technological features of the television system. It covers the location of cameras and accessories, transmission line and facilities, and monitor presentation and orientation. It also includes a comparison of the existing features with alternates of the latest technological design and recommends changes and applications consistent with these developments. The final report on this evaluation has been completed and is being prepared for publication.

Television Information for Research.—Television surveillance to supply research information reveals its qualification as a research tool. However, the determination of the extent and character of the information available and the accuracy with which this information can be obtained must be performed. The nature of the television surveillance phase of the project requires maximum use of this medium by continuous monitoring of the freeway.

This leads to further research to determine the qualifications and limitations of the personnel who are engaged in monitoring freeway traffic. It is necessary to determine the observers' abilities and limitations to establish the level of reliability of the information obtained.

It is also important that this research be performed for the benefit of other agencies should they desire similar installations throughout the country. In addition, it is necessary to research available methods for recording information that is visually obtainable from the monitors. This, of course, involves much experimentation and use of present facilities, such as photographic equipment and, possibly, video taping.

The following studies are under way for this purpose:

1. The scope and limitations of freeway traffic information available through television.
2. Determination of the accuracy of this information.
3. Methods of recording this visual information.
4. Determination of television observers' abilities and limitations.
5. Investigation of the uses of simultaneous viewing and/or sequential viewing.

Television Surveillance Research Application

Television surveillance has been used extensively to obtain research data for many studies. Considerable discussion has already been presented on the research potential of this system. The following discusses the studies involving television observations in the performance of research.

Shoulder Usage on an Urban Freeway.—Research of shoulder usage was the first study in the project in which television provided the primary means of obtaining data. Its general objective was to determine the extent and characteristics of shoulder usage on an urban freeway. The particular objectives were to study the following:

1. Amount of shoulder usage on some rate basis such as vehicle-miles per mile or per hour.
2. Use by type of vehicle.
3. Length of stay.
4. Reason for using the shoulder.
5. Assistance received.
6. Other vehicles involved in a given incident.
7. Relation of findings to other shoulder usage studies.

Trained observers watching the monitors obtained data excluding volume information. When a shoulder usage was observed, the time and location were also recorded using the camera field and direction of travel as reference points. The reason for the stop was determined entirely from the observer's evaluation of the incident. If there was no obvious reason for stopping, the cause was listed as undetermined. No attempt was made to determine the actual reason for stopping because a part of the study was to determine the length of the stay under normal conditions. Traffic data were collected from automatic vehicle detectors and recorded at specified times to determine the vehicle-mile information.

The field studies were conducted in May and August 1961. No attempt was made to determine the number of incidents that was missed by the observers and accuracy is assumed, subject to the completion of an observer evaluation study. It is known, however, that incidents were missed, so that the results are on the conservative side.

Shoulder usage has never been studied as fully as on this project. The work could not have been performed without the television system. The results have already produced benefits inasmuch as the data were used in deciding to include refuge shoulders on the high-level bridge over the Rouge River in Detroit. They have also been used as a basis for a parallel study on the Illinois Surveillance Project in Chicago. However, the Chicago study does not have television surveillance.

Lane Change on an Urban Freeway.—The purpose of the study was to determine and analyze by section vehicle lane changes, which were observed in 13 of 14 camera fields from the monitors. All lane changes by type of vehicles were observed in each field by observers during weekdays for an off-peak hour and a peak hour. Morning peak hours were observed in the southbound direction, and afternoon peak hours in the northbound. Volumes of traffic by type of vehicle were also obtained from the monitors and recorded manually for each camera field on a comparable weekday for the same 1-hr periods.

Inasmuch as the length of roadway required for lane change depended on several factors, lane change movements were recorded in the field in which they were started. The length and end location of the change were not considered. Televison provided an excellent means of obtaining extensive data which may particularly assist in the determination of relationships between lane changing and geometric features. Additional research is contemplated on the effects of the control system on lane changes.

The data from this study have found immediate use. They have been applied by Cook County, Ill., traffic officials in the special problems of design and location of freeways and freeway ramps.

Measuring Travel Time by Television Surveillance.—One of the first research studies performed was the determination of the ability to measure travel time from television surveillance. It was considered that, if the travel time of any vehicle could readily and accurately be so obtained, movement of vehicles or groups of vehicles through surveillance area could be surveyed relative to speed, delays, stoppages, and lanes traveled, and classified by types of vehicles. The study was conducted for a

5-day period in April 1961 by using several observers at the control center who timed two test vehicles on the freeway, passing through television camera fields.

The primary objective on the first day of the study was observation of the test vehicles to determine the accuracy in timing vehicles from a monitor. While the test vehicles were on their return trip in the unmonitored direction, random vehicles were selected and timed through the study area.

On the other four days, the test vehicles were not timed; only randomly selected vehicles were observed and timed. The test vehicles, however, continued their runs each day during the study periods, and recorders in the vehicles recorded the time of passing predetermined reference points.

Three different travel time study techniques were employed in the test vehicle runs: the following car method and the floating car method (both throughout the week); and (on the last day) some maximum car runs. Vehicle type, weather, direction, pavement condition, and date were also recorded. Standard passenger cars were the major sampling, with minor coverages of other vehicle types. Vehicles were chosen starting in various lanes. Some observers became proficient to the point that they could individually observe the progress of the vehicle past each location marking and also record the time to the nearest second on the control room clock. For other observers it was necessary to have a recorder working with them to log the times on data sheets. During the study hours, recordings were taken each minute of the volume, density, and flow speed in each lane from the Chicago Boulevard detectors.

Comparisons made between the travel time as recorded by the test vehicles and that

Figure 2. Median lane closure, Gladstone, before phase.

obtained from the monitors confirmed the reliability of securing travel times of vehicles by television. The results showed great similarity between monitor-observed timing and the timings of the test vehicles. In fact, 3 sec was the greatest variation for all runs under 6 min.

In addition, the travel time results were used as a means of evaluating the traffic control system. Other information useful to other studies was also obtained—including lane changing. Also, statistical methods and computer application will be used to determine the possibility of sampling travel time to obtain representative values. Further study is to be conducted.

Time Savings in Detection of Incidents. —Another aspect is the aid television provides in the detection, evaluation, and the dissemination of information on freeway incidents, such as accidents and vehicle breakdowns. A study now in progress has the specific objective of determining the time savings derived from television surveillance whenever such incidents occur. This benefit can be translated into convenience, efficiency, and safety. Before installation of the television system, notification of any incident was either by an interested motorist in calling the police or by the police on routine patrols. Police records have supplied information on the time involved in the notification and the arrival of assistance vehicles to the scene.

With television surveillance it is possible to detect the incident readily and notify police or emergency vehicles. Time savings will thus accrue for the vehicle involved in the incident and for the total freeway traffic, because assistance vehicles will arrive sooner and the disabled vehicle will be moved to the shoulder sooner, thus reducing traffic delay.

Figure 3. Median lane closure, Gladstone, after phase.

The television observer directs the proper assistance vehicles into the area and the information concerning the actual location is of assistance to the police. The control center is equipped with a direct phone line to the police department radio dispatcher.

In this study benefits accrued from the television in the way of time savings to the motorist and the disabled vehicles and to the total freeway traffic can be easily measured. Final results will be available in the near future.

Effects of Constricted Flow on Freeway Traffic. —Constricted flow is a situation in which one lane or more is blocked or partially blocked, reducing the number of traffic lanes. This constriction is created by various situations, such as an accident, a disabled vehicle, or maintenance crews working. The objective of this study is to determine the effects of lane constriction on traffic volumes and lane capacity. Data were obtained before operation of the freeway signal system in order to measure the effect and benefits of the system in such traffic situations.

In cases where maintenance crews closed a portion of one lane, the method and time of closing were taken into account, as these two factors reduce the normal volumes of traffic at the location of the constriction. From television surveillance, on-the-spot observations can be made whenever such constrictions occur, and the method of closing lanes, their location, and the equipment being employed by the crews can all be studied to determine effects on normal operation. From this study, it may be possible to initiate procedures for closing a lane for maintenance operations in order to achieve better efficiency and lessen the reduction in traffic flow.

In the normal or conventional methods of lane closure, warning is provided by

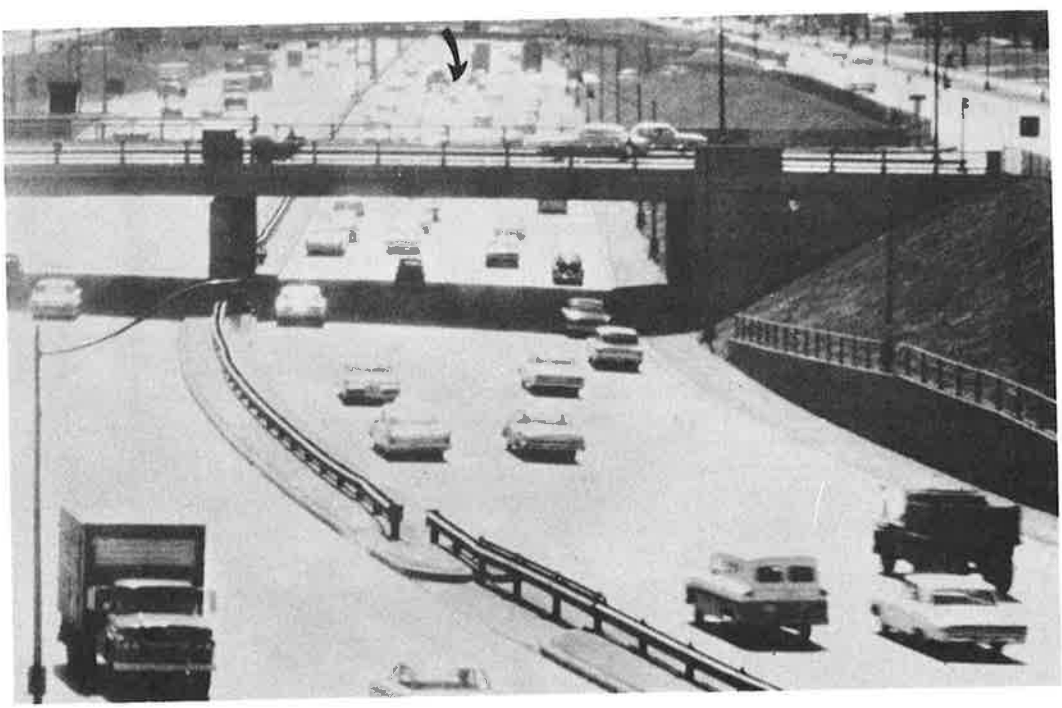


Figure 4. Middle lane closure, Gladstone, before phase.

advance signing plus a flasher trailer and barricades. With the use of the advance signing, it is anticipated that flow of traffic out of the closed lane will be more immediate because warning can be provided far in advance of the particular location. A constricted flow situation could not be planned or scheduled for this study, and data are to be collected whenever a situation occurs.

The before information has been completed. The after information from use of the control system and lane signals has also been completed, and comparison of these data will offer a measure of the effectiveness of a lane signal system. When constricted conditions occur, speed information is obtained wherever possible as are volume counts into, through, and beyond the constriction, and classification of vehicles. To correlate these data taken during constricted flow conditions with normal flow, sample volume counts are taken at the same location at approximately the same time on a day when no constriction is present. Preliminary data on this study have been prepared, and the use of this information will point out any benefit of lane control signals.

Preliminary results show that the average lane volumes in vehicles per minute passing a constriction have been consistently higher (20%) with the use of the control system lane signals. Speeds of vehicles and average lane speeds passing the constriction have also been consistently higher (by 50 to 60%). This improvement is, of course, due to the advance warning lane signals which allow vehicles to move under free-flowing conditions into an open lane.

Evaluation of Traffic Control System

A major area of research has been directed toward the evaluation of the traffic

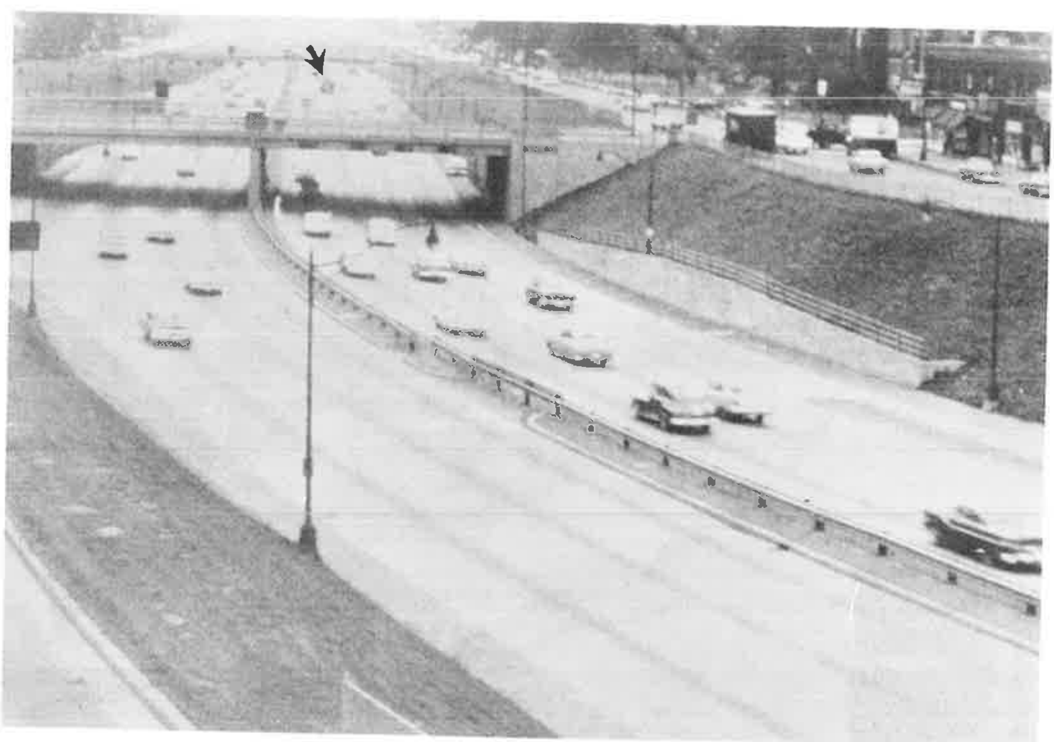


Figure 5. Middle lane closure, Gladstone, after phase.

control system. This system consists of lane signals, speed signs, and ramp closure signals. It merits special research effort because it is the first and only control system applied to freeway traffic. Freeway control is a problem that exists in many urban areas where design capacities have already been surpassed to the extent that congestion is a daily occurrence.

Since May 7, 1962, when the control system was put in operation, research has been conducted to evaluate any benefit derived from improved freeway operation. Preliminary results indicate that improvement in freeway operation, and thus freeway capacity, can be expected from its use. The effect extends beyond the limits of the study sections; its influence can be noted in the areas immediately adjacent.

The results of the research were obtained from specific studies directed toward the investigation of certain phases of the control system: lane closures, constricted flow situations, and travel time.

Lane Closures. —Before installation of the control system, lane closures were introduced in the traffic stream by the use of a maintenance vehicle. Traffic information was obtained for comparison with like situations after installation of the control system. Observations were made from the control center, and the traffic information recorded included volumes, speeds, lengths of back-ups and delays at the closure, the number of vehicles in the closed lane, the number of lane changes, and the distance from the closure at which the lane changes were initiated. Sufficient information was also gathered to determine reduction in delays and erratic driving to measure the effectiveness of the system. In addition, motion pictures taken of the lane closure areas from a high

Figure 6. Stalled vehicle in median lane with characteristic traffic congestion.

vantage point provided visual records of the conventional method of closure as well as closure by the lane control signals.

The purpose of this study was to measure the comparative effectiveness of moving volumes of urban traffic past a lane closure using such conventional methods as flasher trailer cones, road signs, and barricades as opposed to the lane signal system. Lane closures were established for both directions of travel downstream from the sensing equipment at the Calvert and Chicago locations so that approaching volumes and speeds were recorded in three- and four-lane sections.

The before and after phases were conducted at identical locations to obtain similar conditions. The before phase was conducted in April 1962, and the after phase in July 1962. The after portion will be repeated when the ramp closure signals are installed.

The information obtained at the lane closures is as follows:

1. Time, deviation, and location of closure.
2. Average approach volumes in vehicles per minute (vpm).
3. Average speeds of vehicles in open lanes past closure.
4. Average travel speeds in camera areas upstream and downstream of closure from travel times.
5. Lane changing in areas adjacent to closure upstream in average vehicles per minute.
6. Vehicles per minute stopped in closed lane.

The closures were made at Gladstone in the southbound and at Webb in the northbound roadway. The Gladstone closure is in a four-lane section; the Webb closure, in a three-lane section.

Figure 2 shows the lane closure (median lane) for the before phase at Gladstone. Figure 3 shows the same closure at the same time of day after the signals were in operation.

Figures 4 and 5 show a closure in the middle lane for the before and after periods, respectively. Figure 6 shows a stalled vehicle in the median lane and the characteristic

TABLE 1

LANE CLOSURE COMPARISONS

Signals Installed	Approach Volume		Vehicles Stopped in Closed Lane (vpm)		Speed by Closure (mph)	Lane Change Location	
	Vpm	Vpm/ Lane	Range	Avg.		Distance from Closure (ft)	Percent of Changes
(a) Gladstone Southbound Traffic, 4-Lane Section, 3 Closures[1]							
Before	64	21	5-23	11	31	0-400	93
						1,000-1,500	7
After[2]	68	22	0-2	1	51	600-1,000	31
						1,000-1,500	69
(b) Webb Northbound Traffic, 3-Lane Section, 2 Closures[1]							
Before	61	30	2.3-4.3	3.3	30	0-250	92
						350-1,500	8
After[2]	80	40	0.8-2.2	1.5	31	200-900	37
						900-1,500	63

[1] One lane closed each closure.
[2] Advance lane signal 900 ft before closure.

congestion of traffic. No signals are in operation and no warning is provided the approaching traffic.

The preliminary results from the lane closure comparisons are given in Table 1. A definite trend is apparent which reveals increased freeway operation from the use of the lane signals during periods of lane closure. From the table, the following trends can be pointed out:

1. Lane changing from the closed to an open lane was initiated by motorists in some instances farther in advance of the closure with signals than without. At Gladstone, for the before condition, 93 percent of the lane changes took place within 400 ft of the closure by the conventional methods, whereas 69 percent of the lane changes during the after phase took place between 1,000 and 1,500 ft in advance of the closure. The 7 percent of lane changes in the before phase was indicated from the lane change study as being normal for the areas studied. The majority of the 31 percent lane changes in the after phase that began between 600 to 1,000 ft occurred in the distance from 700 to 1,000 ft. The advance warning permitted motorists to size up the situation ahead, adjust their position, and move into the open lane in sufficient time not to be trapped immediately at the closure.

2. The Gladstone closure indicated a slight increase in volumes approaching the closure (64 to 68 vpm); however, an increase in speed of vehicles past the closure ranged from 40 to as high as 60 percent.

3. At Gladstone, the range of vehicles stopped or trapped by closure was considerably reduced when the lane signals were in operation from 11 to 1 per minute of duration of closure.

4. At the Webb closure, the approach volume was considerably increased at the time of the after closure over the before as indicated by the approach volumes of 61 to 60 vpm. At the same time, the speed past the closure was approximately the same.

5. The lane change at the Webb closure indicated that the point of initiation of the lane change moved back with the lane signals in operation. This change resulted under the heavier volume conditions—92 percent began between 0 and 330 ft in advance of closure without signals, but 63 percent of the lane changes began between 900 and 1,500 ft with the signals in operation.

6. At Webb, there was also a reduction in the number of vehicles stopped or trapped immediately at the closure when the signals were in operation.

The handling of lane closures when the signals were in operation was a considerable

TABLE 2

CONSTRICTED FLOW COMPARISONS

Section	Signals Installed	Average Capacity	
		Lane (vph/lane)	Hourly[1] (vpm/lane)
3-Lane	Before	25.70	1,542
	After	35.75	2,142
	Increase	10.05	603
	% Increase	39.1	
4-Lane	Before	22.2	1,333
	After	29.4	1,764
	Increase	7.2	432
	% Increase	32.4	

[1] Expanded.

improvement over that during use of conventional methods. These, of course, are preliminary results, but they do indicate a trend toward improved operation with the control system.

Evaluation of the other elements of the control system (the speed signs and the ramp closure signs) has not been completed. The evaluation of the speed signs is under way. The ramp signals are to be installed soon, and evaluation of the control system following their installation will be completed.

Constricted Flow Situations. —The results of the constricted flow study were derived from closures caused by maintenance vehicles, stalled vehicles, or accidents. As these incidents could not be scheduled, only a limited amount of traffic information was obtained because of manpower limitations at those times. The incidents occurred in both three- and four-lane sections of the freeway, and all data were collected from television surveillance. Results from incidents created by maintenance before and after the operation of the lane signals permit comparison with those from the scheduled lane closures.

During the incidents constricting flow, lane volumes passing the closure before and after lane signal operation were recorded. The comparisons cover 14 incidents before the signals and 8 incidents after. Freeway volumes were compared to assure similar traffic conditions. Table 2 gives a 39 percent increase in lane capacity for three-lane sections and a 32 percent increase for the four-lane section during operation of the lane signals. In the four-lane section, the shoulder lane is reserved for exiting traffic only

TABLE 3

COMPARISON OF AVERAGE TRAVEL TIMES[1] BEFORE AND AFTER CONTROL SYSTEM INSTALLATION

Location	Car Method	Time Period	Avg. Travel Time (min)	Percent Reduction
Study section	Follow	Before peak	5.86	
		After peak	5.29	
		Reduction	0.57	9.7
		All before	3.98	
		All after	3.80	
		Reduction	0.18	4.5
	Floating	Before peak	6.17	
		After peak	4.88	
		Reduction	1.29	20.9
		All before	4.02	
		All after	3.68	
		Reduction	0.34	8.4
Extended areas[2]	Follow	Before peak	3.24	
		After peak	1.86	
		Reduction	1.38	42.6
	Floating	Before peak	3.10	
		After peak	1.94	
		Reduction	1.16	37.4

[1] Test vehicles only, northbound direction.
[2] Beyond study section (Merrick to Grand Trunk Railroad).

and is so signed. Thus, the increase in capacity for this section is actually higher than presented, as the average lane capacity reflects those vehicles in the shoulder lane for exiting as well as through traffic.

The preliminary results show a definite increase in freeway operation during such incidents which can be attributed to the control system. Continuation of this study is planned.

Travel Time Comparisons. —The travel time study was repeated following the installation of the control system. The basic plan of the study was to determine the feasibility and reliability of securing travel times through a 13-camera study area from television monitors. The weeks' study in April 1961 showed this could be done accurately. This was again confirmed in an after phase in July 1962. This after phase took place while the lane and speed signals were being used to maintain smooth maximum flow of traffic and to give maximum assistance to the traffic.

Use of several operators for the control system operation introduced additional variables which could not be measured. The study hours in the after phase were the same as in the before phase. In addition to the various passenger vehicles and trucks observed in the study, a State test vehicle again made runs through the study area and logged travel times in both directions at each camera location and at several points beyond each end of the study section. This allowed comparisons in the study area as well as in adjacent areas 1 mi to the north and 0.7 mi to the south. The data were obtained from computer tabulations coded on IBM cards.

TABLE 4

COMPARISON OF AVERAGE TRAVEL TIMES[1] BEFORE AND AFTER CONTROL SYSTEM INSTALLATION

Location	Car Method	Time Period	Avg. Travel Time (min)	Percent Reduction
Study section	Follow	Before peak	4.92	
		After peak	3.72	
		Reduction	1.20	24.4
		All before	3.95	
		All after	3.30	
		Reduction	0.65	16.5
	Floating	Before peak	4.83	
		After peak	3.88	
		Reduction	0.95	19.7
		All before	3.74	
		All after	3.35	
		Reduction	0.39	10.4
Extended areas[2]	Follow	Before peak	3.29	
		After peak	2.85	
		Reduction	0.44	13.4
	Floating	Before peak	3.47	
		After peak	2.91	
		Reduction	0.56	16.1

[1] Test vehicles only, southbound direction.
[2] Beyond study section (Baylis to Glendale).

Tables 3 through 7 compare travel times to indicate any benefits attributable to the control system. Freeway volumes for the before and after periods were compared closely to detect the effects of any variable volume conditions.

Tables 3 and 4 give travel time comparisons by direction, driving method, TV-viewed area comparisons, and adjacent areas. Peak-period comparisons are separated from total observed periods (included off-peaks) and made for the test vehicles only.

Table 5 gives summaries of travel time comparisons for each direction of travel, showing the reduction in travel time effected in the areas immediately outside the study section. The results were obtained during control system operation. They are based on 800 travel time samples in the before period and 850 in the after. Indications are that definite reduction in travel time can be effected with the control system operation.

Travel time reduction can be expressed in time savings to motorists. Time savings present a more realistic factor which simplifies the understanding of the benefit of control system operation. Table 6 gives time savings based on travel time reduction, and expanded to total volumes through the study section, for each direction and for the areas

TABLE 5

TRAVEL TIME COMPARISON

Traffic Flow	Location	Time Period	Reduction in Travel Time (%)	
			Follow Car Method	Floating Car Method
Northbound	Study section	Peak	9.7	20.9
		All	4.52	8.45
	Extended area[1]	Peak	42.6	37.4
Southbound	Study section	Peak	24.4	19.7
		All	16.5	10.4
	Extended area[2]	Peak	13.4	16.1

[1] Beyond study section (Merrick to Grand Trunk Railroad).
[2] Beyond study section (Baylis to Glendale).

TABLE 6

ESTIMATED TIME SAVINGS APPLIED TO STANDARD PASSENGER VEHICLES ONLY, STUDY SECTION

Location	Length (mi)	Direction of Traffic	Travel Time Sample	Time Period	Time Savings[1] (sec)	Total Pass. Vehicles	Total Est. Time Savings per Day (hr)
Study section	3.2	Northbound	500	14-hr	19	520,000[2]	273
		Southbound	350	14-hr	59	600,000[2]	880[2]
Merrick to Grand Trunk	0.7	Northbound	-	3:30-5:30 PM	34	11,200[3]	112
Baylis to Glendale	1.4	Southbound	-	6:00-9:00 AM	70	12,000[3]	217

[1] Average travel time reduction per vehicle.
[2] For 14-hr period.
[3] Estimated daily.

TABLE 7

AVERAGE SPEED COMPARISONS, TOTAL TRAVEL TIME SAMPLES—ALL VEHICLES

Direction	Average Speed (mph)		Increase	
	Before Signals	After Signals	MPH	%
Northbound	38	43	5	13
Southbound	38	48	10	26.3

outside the study section (passenger vehicles only). The samples were split equally between off-peak and peak periods. Traffic volumes for the 14-hr surveillance are used because the control system operated only for that period of time. The travel time reductions were obtained from IBM computers. Table 6 also gives estimated time savings if average travel time reduction is applied to passenger vehicles for an assumed 14-hr operation period.

Table 7 gives the travel time reduction in average speed comparisons for before and after signal operation. Both directions of travel indicate increases in average speeds. These speeds were computed from travel time samples through the study section.

Traffic Information Collection Equipment

The traffic data collection equipment provides the means of obtaining mass traffic information for research in freeway traffic characteristics and driver behavior. The project is preparing programs for various studies which involve mass data for use of computers. Because some of the studies completed were conducted with manual data collection and analysis, it has become apparent that future research must incorporate

TABLE 8

COMPARISON OF PEAK TRAFFIC VOLUMES BY DAY OF WEEK

Type of Volume	Volume on						
	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun.
24-hour	64,785	63,880	66,265	66,250	63,000	59,411	43,214
Total rush (3 to 6 PM)	16,611	15,280	15,396	16,122	15,318	-	-
Highest hourly	5,815	5,283	5,630	5,629	5,487	5,145	3,721
Average rush hourly	5,537	5,092	5,132	5,374	5,106	-	-
Average daily hourly	2,699	2,662	2,761	2,760	2,624	2,475	1,801
Highest 15-min	1,537	1,405	1,429	1,469	1,423	1,393	1,018
Average 15-min:							
Rush period	1,384	1,273	1,283	1,344	1,277	-	-
24-hour	675	666	690	690	656	619	450
Highest 5-min	525	488	496	517	498	483	370
Average 5-min:							
Rush period	461	424	428	448	426	-	-
24-hour	225	222	230	230	219	206	150
Highest 1-min	114	104	108	113	107	105	87
Average 1-min:							
Rush period	92	85	86	90	85	-	-
24-hour	45	44	46	46	44	41	30

computer programing to avoid the painstaking, tedious, and time-consuming analysis. The possibility of obtaining traffic information simultaneously on volumes, speeds, and occupancy in such a quantity at several points on the freeway can be realized to the maximum degree with computer programing.

The present data collection equipment consists of sensing equipment and computers that collect data at two locations for three lanes in both directions. Such information will be useful in controlling traffic on the freeway by providing complete information on the character of traffic flow.

Freeway Volume Characteristics and Classification. —The research study on freeway volume characteristics and classification is an example of the use of the data collection equipment and illustrates the need for computer application. Its purpose is to obtain the basic volume information over the freeway study area in order to determine volume characteristics, volume trends, and patterns to be used as a basis for comparison of traffic after the signal control system is installed. The information will be used to determine freeway traffic characteristics and the reliability of sampling, thereby eliminating the need for obtaining complete sets of traffic data for future studies.

To reveal the characteristics of freeway traffic fully, it is important to understand how this traffic is affected by the various types of vehicles in the traffic streams. Each

TABLE 9

COMPARISON OF PEAK TRAFFIC VOLUMES

Period	Percent of	Volume				
		Mon.	Tues.	Wed.	Thurs.	Fri.
Rush[1]	24-hr total	25.6	23.9	23.2	24.3	24.3
Peak:						
60-min	24-hr total	9.0	8.3	8.5	8.5	8.7
	Rush period	35.0	34.6	36.6	34.9	35.8
15-min	24-hr total	2.4	2.2	2.2	2.2	2.3
	Rush period	9.3	9.2	9.3	9.1	9.3
5-min	24-hr total	0.81	0.76	0.75	0.78	0.79
	Rush period	3.2	3.2	3.2	3.2	3.3
1-min	24-hr total	0.18	0.16	0.16	0.17	0.17
	Rush period	0.69	0.68	0.70	0.70	0.70

[1] For northbound flow occurs from 3 to 6 PM.

TABLE 10

COMPARISON OF PRESENT PEAK VOLUMES TO DESIGN CAPACITY

Period	Percent Volume Above Design Capacity						
	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun.
Rush	23.0	13.2	14.0	19.4	13.5	-	-
Peak:							
60-min	29.2	17.4	25.1	25.1	21.9	14.3	-[1]
15-min	36.6	24.9	27.0	30.6	26.5	23.1	-[1]
5-min	40.0	30.1	32.3	37.9	32.8	28.8	-[1]
1-min	52.0	36.0	44.0	50.7	42.7	40.0	16.0

[1] Volume below design capacity.

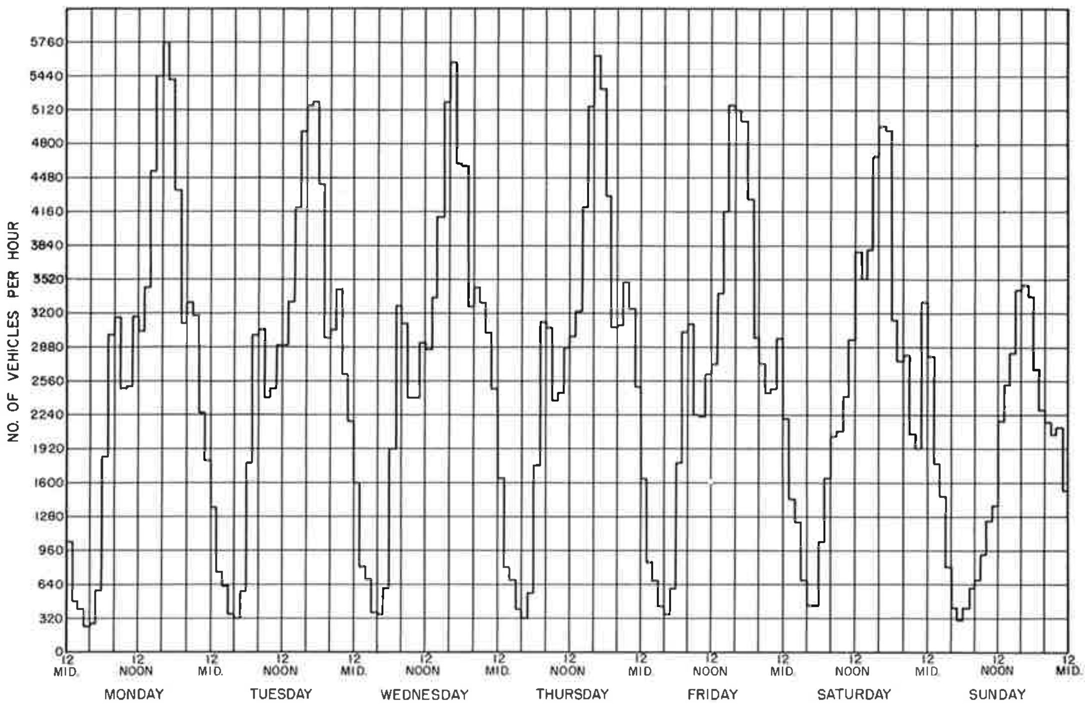


Figure 7. Hourly volumes for 7 days, John C. Lodge Freeway, outbound.

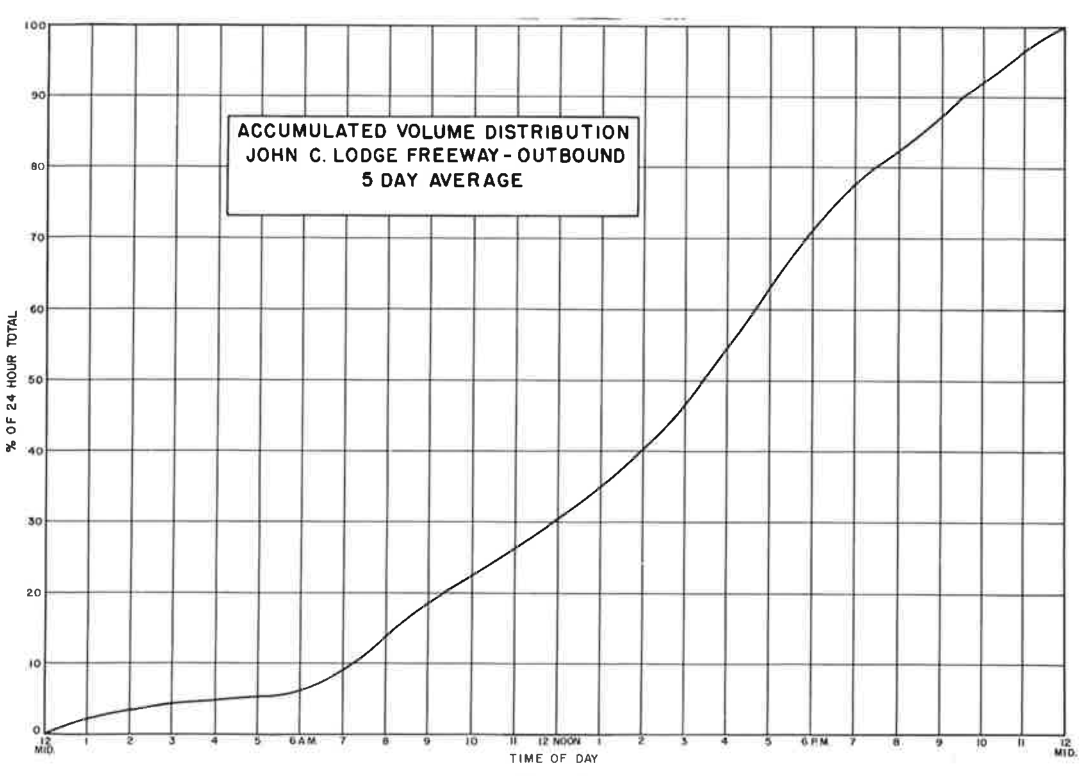


Figure 8.

type vehicle has individual operating characteristics which introduce certain influences on the traffic stream. It is important to know what proportion of the traffic stream is made up of each type of vehicle.

Volume classifications were also determined for various lanes, on- and off-ramps, and different sections of the study area. The major portion of the study was conducted with the use of the automatic sensing equipment to obtain 24-hr volume counts on the freeway proper. This equipment had to be supplemented with machine counts on all ramps and with manual classification counts for nine vehicle types.

A supplemental phase of the study determined that it was possible to obtain accurate traffic information, volume counts, and vehicle classification by use of television. Television observation was particularly helpful in obtaining sampling counts over short periods of time for determining reliability in sampling future traffic volumes on the freeway. Programs are under way using computers to handle the mass data available from the study.

Tables 8 through 10 and Figures 7 and 8 give some indication of volume conditions on the freeway. The data were collected over seven consecutive days for the northbound direction only, entirely by use of the automatic sensing equipment and detectors.

Table 8 compares peak traffic volumes by day of week. Comparisons are made by 1-hr, 15-min, 5-min, and 10-min periods. Table 9 compares the percent of peak volumes according to 24 hr, and the rush period from 3:00 to 6:00 PM for the weekdays only. Table 10 compares present peak volumes to design capacities of the freeway. The comparison is made for weekdays by percent increase over design capacities.

Figure 7 shows the hourly volumes for seven days. Figure 8 shows the accumulated volume distribution of traffic for five weekdays collected thus far. The curve shows the 5-day average by percent of 24-hr total.

A program of continuous collection of traffic data for computer application is in progress.

CONCLUSIONS AND RECOMMENDATIONS

The preliminary conclusions of this study are as follows:

1. The television system has become extremely important in the operation of a freeway control system. The benefit of continuous viewing of the freeway for the efficient operation of such an intricate and complex control system cannot be stressed enough, as exemplified by speedy detection of emergency situations.

2. The television system provides an opportunity to obtain valuable experience for studying freeway traffic from continuous visual observation of a length of freeway, and also for the accumulation of research information that cannot be obtained in any other manner.

3. The traffic control system has indicated that it will provide increased freeway operation efficiency based on the following: (a) More efficient handling of lane closures as evidenced by increased capacity (35 to 40%), advanced warning resulting in advanced merging and in the reduction in number of vehicles trapped at a closure. (b) Significant reduction in travel time under control system operation during incidents, lane closures, and normal conditions (5 to 25%).

This is a preliminary evaluation based on research activity to date; further research is required and recommended, particularly in the area of control system evaluation. A total evaluation will be necessary after installation of ramp signals, whose effect could be significant.

Time has not permitted the proper evaluation of the speed control phase on which the absence of the ramp control has a direct bearing. Further, with the additional information from individually-controlled, equally-spaced speed detectors, speed control should be more realistic and efficient.

ACKNOWLEDGMENT

The author wishes to acknowledge the assistance of the following Michigan State Highway Department personnel in the preparation of this report: W. J. Roth, "Travel Time

Study," and "Evaluation of Control System Study"; Charles Richard, "Television System and Traffic Surveillance"; Conrad Dudek, "Freeway Volume Characteristics"; and Edward Gervais, Project Manager, John C. Lodge Freeway Surveillance Project. Information and data from specific research studies assigned to these persons provided the basis for the evaluations contained herein.

Effect of an Expressway on Distribution of Traffic and Accidents

FREDERICK F. FRYE, Research Analyst, Chicago Area Transportation Study, Chicago, Ill.

• THIS PAPER summarizes the results of a test of the effect of an expressway on the traffic flow and accident experience on all streets in an area. The project is based on an examination of traffic volume and reported motor vehicle traffic accidents before and after an expressway is constructed and opened. Direct measurements of both variables were made in a 16-sq mi area defined as the Congress Expressway study area (Fig. 1). The Congress Expressway was opened to through traffic in October 1960. Therefore, the before time period is considered the year 1959; the after period, 1961. Accident records for two comparable four-month periods were examined to determine certain accident characteristics; for example, precise location by street type and direction, day, and hour of occurrence.

The study of the traffic flow in the study area is actually independent of the accident study. However, the combining of the traffic flow data with accident data makes it possible to measure the effect of an expressway on accident rates and costs.

Changes in traffic volume on segments of the arterial system were determined and are presented in the form of a plus-and-minus flow map. This map reflects the effect of the expressway on east-west arterial streets, and the effect of expressway ramps on north-south arterials. The average daily traffic (ADT) is distributed by hourly increments to measure the ability of the expressway to reduce congestion on arterials during the peak hours of vehicular travel.

The annual average daily traffic (AADT) on local streets was estimated through a sampling technique. Any change in the AADT and associated change in the number of accidents on local streets are discussed later.

Frequencies of reported accidents that occurred in the study area during the two periods are compared as a measure of the effect of an expressway on accident experience in the area. The collected accident data are related to traffic volume figures in the form of accident rates (accidents/vehicle-miles of travel). In addition, the accident rates are converted into accident cost rates, and an estimate of the saving in accident costs as a result of the introduction of an express facility is made.

Three areas without expressways were selected as control areas. Within these control areas, changes in traffic volume and accident experience were determined for 1959 and 1961 and compared to the data collected in the study area.

This report is another step in the analysis of the relationship of traffic volume and accident experience. Two previously published reports (1, 2) discussed the relative safety of local, arterial, and expressway facilities in the city of Chicago. It was also discovered through some preliminary work (3) that an expressway can influence the accident rate in a large area surrounding the expressway. This report measures the effectiveness of highway planning in reducing the number of motor vehicle traffic accidents.

TRAFFIC VOLUME IN THE STUDY AREA

The area selected for study is a relatively high traffic volume area. The ADT on its arterials was 16,430 in 1959 as compared to an overall average of 12,700 for the

Paper sponsored by Committee on Speed Characteristics.

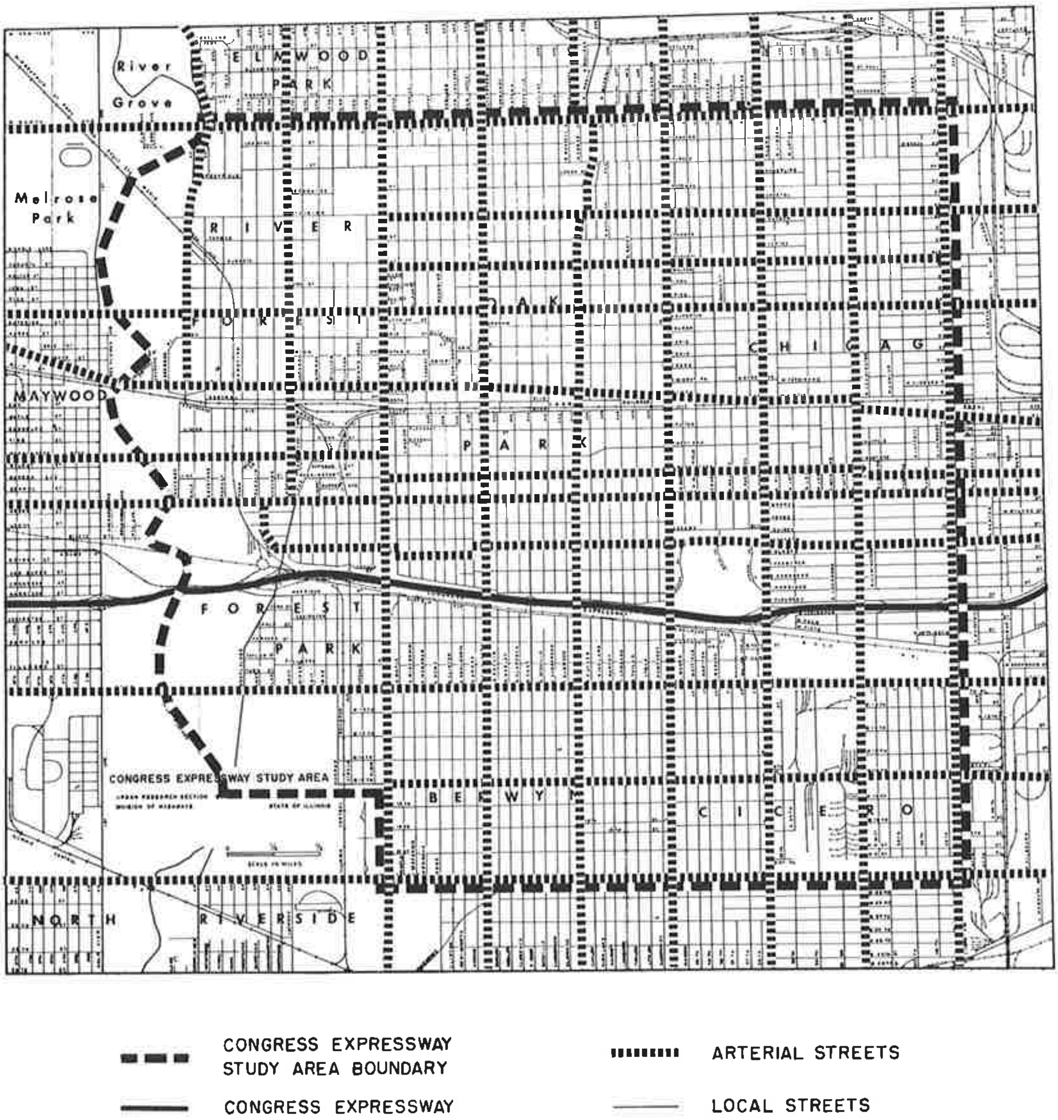


Figure 1. Congress Expressway study area showing streets by type, limitation of area, and political units.

Chicago Area Transportation Study (CATS) area. On local streets (residential), the ADT was 1,310 in 1959 as compared to 1,230 for the CATS area. The high volumes are caused by the high population density of Oak Park, which is in the center of the area under study, and by the continuing growth of motor vehicle travel from the expanding western suburbs. To handle this traffic more safely and efficiently, the expressway was designed and constructed.

The effect of an expressway can best be determined by understanding how traffic is distributed on a network of all streets in an area before and after it is opened to traffic. The CATS network was selected as the most accurate and readily available definition of streets into local, arterial, and expressway categories. The system as divided into street categories is shown in Figure 1. Comparisons of traffic volumes in 1959 and 1961 will be made subsequently.

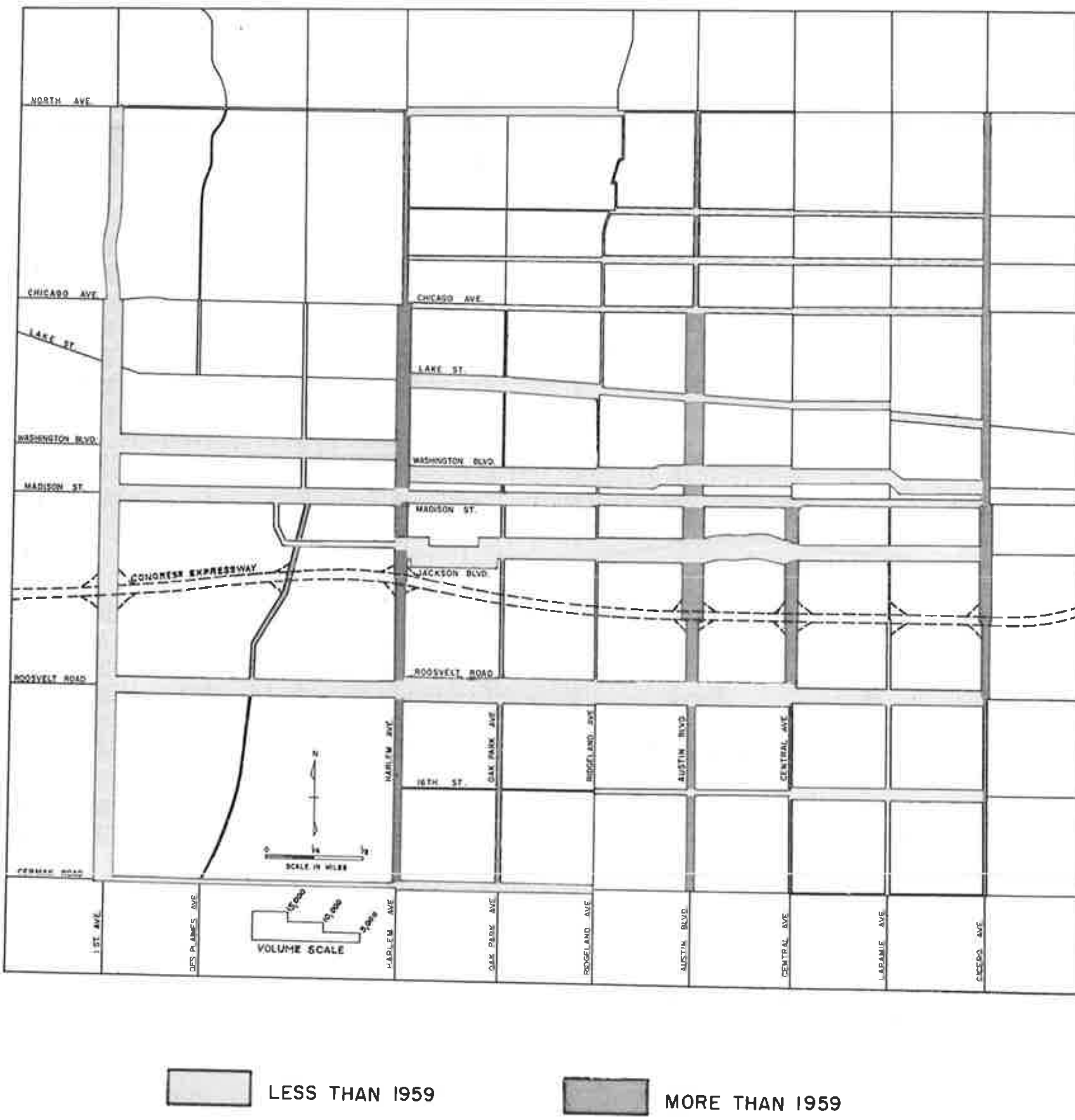


Figure 2. Redistribution of traffic volume on average weekday on arterial streets due to opening of Congress Expressway.

Distribution by Street Type

In 1959 the expressway extended 6 mi from downtown Chicago to Laramie Avenue with only a ½-mi link within the study area. This short link, however, served more as a long ramp to and from the expressway, and did little to benefit the immediate area. The bulk of the traffic was being carried by the arterial and local streets in the area. During the two-year period 1959-61, traffic volume in the area increased 21 percent. The entire increase was absorbed by the expressway, and a portion of the traffic on the arterial and local street systems was diverted to the expressway. The daily vehicle-miles of travel (VMT) by street type are given in Table 1, as well as the ADT and percentage distribution of traffic by street type.

The total miles traveled within the area on an average weekday increased from

TABLE 1

DISTRIBUTION OF TRAFFIC IN CONGRESS EXPRESSWAY STUDY AREA ON AVERAGE WEEKDAY BEFORE AND AFTER EXPRESSWAY CONSTRUCTION

Street Type	Total VMT		Average Daily Traffic		Percent of Total Travel	
	1959	1961	1959	1961	1959	1961
Local	331,000	310,000	1,310	1,225	20.8	16.1
Arterial	1,224,000	1,172,000	16,430	15,730	77.1	61.0
Expressway	33,000	440,000	66,000	110,000	2.1	22.9
Total	1,588,000	1,922,000	4,850	5,800	100.0	100.0

1,588,000 in 1959 to 1,922,000 in 1961. This increase is greater than would be expected in a two-year period. The increase is the result of four interrelated elements:

1. Natural Growth.—There is historical evidence of a natural growth pattern of traffic volume in the study area of 3.5 percent per year. This is determined by referring to traffic volume counts made in 1953, 1956, and 1959.

2. Induced Traffic.—When superior traffic carrying facilities are introduced in an area, persons are induced to travel more (make more or longer trips). The amount of induced traffic in the area cannot be determined, but logic dictates that a portion of the 21 percent increase should be attributed to inducement.

3. Diverted Traffic.—Diverted traffic is usually thought of as traffic transferred from one traffic-carrying facility to another. In this report, the term is also used to define traffic that existed outside the study area in 1959 but has been diverted to streets within the area. This does not imply that all diverted traffic uses the expressway. The expressway has "drawn" traffic from nearby parallel arterials and has "freed" them from congestion. Traffic that previously used parallel arterials outside the area now is diverted to arterials within the area.

4. Adverse Travel.—The speed and safety possible on an expressway will influence people to "go out of their way" to use such a facility. The distance that they will go out of their way is dependent on the length of their trip. Experimental work conducted on the optimum spacing of expressways has indicated that 0.1 mi of additional travel is made for 1 mi of over-the-road distance by expressway users with no change in origin and destination. The additional 0.1 mi is called adverse travel.

The relative importance of the four elements that contributed to the increase in traffic in the study area is discussed in the Appendix of a CATS report (4). Available data indicate that the diversion of traffic from areas outside of the Congress Area contributed about 50 percent of increase in traffic from 1959 to 1961.

Changes on Local and Arterial Streets

Traffic volume on local and arterial streets in the study area decreased 6.3 and 4.2 percent, respectively. As would be expected, the most noticeable decreases took place on east-west arterial streets which parallel the expressway. North-south arterials had increases due to the overall increase in traffic and the effect of large volumes of traffic exiting and entering the expressway ramps. The redistribution of traffic can be seen by referring to the plus-and-minus flow map (Fig. 2).

Local Streets.—One problem of the highway planner is to reduce the traffic and the number of accidents on local streets. A previous report (2) stated that the accident rate (accidents/VMT) on local streets was more than double the rate on arterials. The reasons for the higher rate are inherent design characteristics which are difficult and expensive to correct.

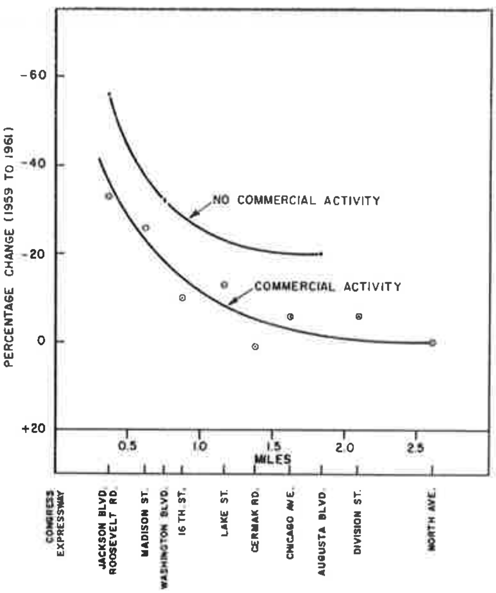


Figure 3. Percentage change in VMT on east-west arterial streets by distance from Congress Expressway.

A traffic study of Oak Park was conducted in 1959 by Barton-Aschman Associates (4). The study included a thorough examination of the traffic volume on local streets in Oak Park. The following is one of the major conclusions of that study:

> Many of the major traffic routes in Oak Park are presently overloaded, with congestion as the most obvious result. An additional result, however, is that nearly one-half of the total mileage of local streets is carrying through traffic seeking to escape this congestion.

The study area is laid out in a gridiron street pattern. This pattern encourages the use of local streets for through trips. Studies conducted in California, one in the City of Richmond (5) and the other in Los Angeles County (6), concluded that the gridiron pattern of local streets is more accident inducing than a limited-access pattern. In an established community, such as the area under study, it is difficult to alter the street pattern. Other means must be used to alleviate the traffic and accident situation on local streets.

An effective way to reduce traffic volume on local streets is to make the arterial network more attractive (through an alleviation of congestion) to through trips. To measure the effectiveness of an expressway in shifting traffic from the local street system to the arterial network (or to the expressway itself), a sample of local streets was counted in 1959 and 1961. The ADT for local streets in the area was reduced 7 percent from 1959 to 1961.

East-West Arterials.—It has been stated previously that the east-west arterials in the study area experienced reductions in ADT. The amount of relief to congested arterials which was derived from this reduction can best be measured by examining where (distance from expressway) and when (time of day) these reductions took place.

Reduction in Traffic Volume vs Distance from Expressway.—The degree to which traffic can be diverted from a parallel arterial to the expressway is dependent on the distance of the arterial from the expressway, and the amount of commercial activity abutting the arterial. Noncommercial arterials (e.g., Jackson and Washington Boulevards) which service residential buildings along the arterial and long-distance through trips had larger decreases in traffic than did commercial-lined arterials, such as Madison Street and Roosevelt Road. This is a logical expectation because the abutting property on Madison Street and Roosevelt Road attracts more trips. The two east-west arterials, North Avenue and Cermak Road, which constitute the northern and southern boundaries of the study area, continued to carry the same volume of traffic in 1961 as in 1959. (This, in effect, is a reduction, because a 6 or 7 percent natural growth increase would be expected.) The relationship of traffic volume decrease to distance from the expressway and abutting property is shown in Figure 3. The arterials have been classified as commercial and noncommercial from observation. The relationship results in two hand-fitted curves.

Hourly Distribution of Traffic on East-West Arterials.—A screenline check of east-west traffic crossing Austin Boulevard by hour of day was made (Fig. 4). There is a similarity in the hourly distribution of traffic on arterials in 1959 and 1961. The total volume for 1961 in the figure is the summation of the arterial and expressway volumes, and is similar, also, to the hourly variation on arterials in 1959 and 1961.

TABLE 2

RELATIONSHIP OF PEAK-HOUR (5 TO 6 PM) TRAFFIC VOLUME TO DESIGN CAPACITY ON EAST-WEST ARTERIALS AT AUSTIN BOULEVARD SCREENLINE IN 1959 AND 1961

Arterial	Peak-Hour Design Capacity	Peak-Hour Volume		Ratio of Peak-Hour Volume to Design Capacity	
		1959	1961	1959	1961
Cermak	1,990	2,070	2,020	1.04	1.02
16th	700	1,240	1,100	1.77	1.57
Roosevelt	1,660	2,180	1,210	1.31	0.73
Jackson	1,220	1,750	980	1.46	0.82
Madison	2,200	2,660	1,450	1.21	0.66
Washington	1,260	2,100	1,220	1.67	0.97
Lake	1,080	1,220	1,000	1.13	0.92
Chicago	1,080	1,400	1,020	1.30	0.94
Augusta	1,200	1,290	700	1.08	0.58
Division	1,330	1,440	710	1.08	0.53
North	2,070	2,510	2,970	1.21	1.43
Total	15,770	19,870	14,380	1.26	0.91

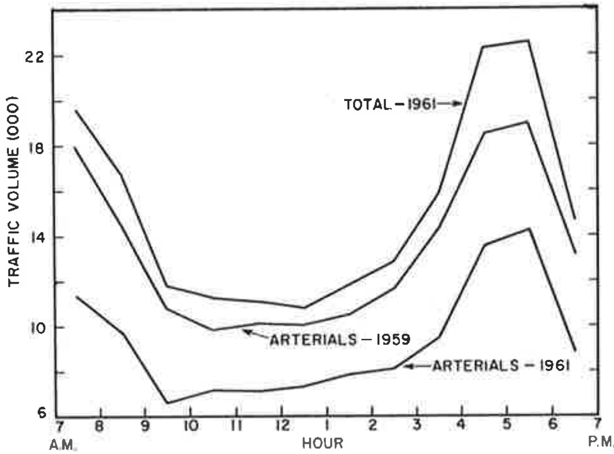


Figure 4. East-west traffic volume crossing Austin Boulevard screenline by time of day, 1959 and 1961.

Inasmuch as the hourly distribution of traffic on arterials in 1959 and 1961 is the same, an examination of peak-hour (5 to 6 PM) benefits derived from the introduction of an expressway will indicate the relative benefits for all other one-hour periods. The benefits can best be measured by relating the 1959 and 1961 arterial volumes to design capacity. The peak-hour design capacity and traffic volumes for 1959 and 1961 are related and the ratio (V/C) has been computed. Table 2 gives the change in this relationship.

In 1959, the east-west arterials from Cermak Road to North Avenue were operating during the evening peak hour at volumes in excess of their design capacity. After the construction of the expressway and the subsequent shift of traffic from the arterial to the expressway, eight of these arterials had a volume-to-design capacity ratio of less than 1.00.

TABLE 3

RELATIONSHIP OF PEAK-HOUR (5 TO 6 PM) TRAFFIC VOLUME TO DESIGN CAPACITY ON NORTH-SOUTH ARTERIALS AT CONGRESS SCREENLINE IN 1959 AND 1961

Arterial	Peak-Hour Design Capacity	Peak-Hour Volume		Ratio of Peak-Hour Volume to Design Capacity	
		1959	1961	1959	1961
Cicero	2,130	1,730	2,290	0.81	1.08
Laramie	1,640	1,790	1,540	1.09	0.94
Central	1,640	900	1,260	0.55	0.77
Austin	1,400	1,100	1,650	0.78	1.18
Ridgeland	1,550	1,200	1,200	0.77	0.77
Oak Park	1,110	1,080	930	0.97	0.84
Harlem	1,550	1,500	1,930	0.97	1.24
Des Plaines	1,000	800	900	0.80	0.90
Total	12,020	10,100	11,700	0.84	0.97

Maximum capacity is defined as the maximum number of vehicles that can pass a point on a roadway in a given period of time without consideration of the quality of the traffic flow. Through relationships of speed to the ratio of volume to capacity of various types of roadways, a more acceptable (based on quality of flow) definition of capacity was devised. This capacity standard is called design capacity.

North-South Arterials.—Expressway ramps greatly affected the north-south arterials by drawing more traffic to them. This is especially true of Cicero Avenue, Austin Boulevard, and Harlem Avenue. This can be examined by relating peak-hour volumes to design capacity on the arterials.

Before the opening of the expressway, the volume-to-design capacity ratio at Cicero Avenue, Austin Boulevard, and Harlem Avenue was below 1.00. The ratios in 1961 given in Table 3 for these three arterials now exceed 1.00. Austin Boulevard and Harlem Avenue were greatly affected, because they have full interchanges with the expressway, and because they are spaced 1½ mi apart. The two arterials, Ridgeland and Oak Park Avenues, which lie between Austin Boulevard and Harlem Avenue had little change in their peak-hour volumes. Also, Laramie Avenue, which previously acted as the western terminus of the expressway, dropped below its design capacity when the pressure was relieved.

VMT ON ARTERIALS

The study area was divided into twelve analysis zones. The change in total VMT on arterials is shown in Figure 5. The percentage change is given for north-south and east-west arterials and for all arterials.

The general influence of the expressway on arterial traffic volume is also shown in Figure 5. As expected, the greatest benefit in traffic volume reduction occurred in the three zones through which the expressway was constructed. The area bordered by Madison Street and Chicago Avenue decreased in total arterial traffic volume mainly because of the reduction on Washington Boulevard, which lost more than 40 percent of its volume. There was a large increase in the traffic volume on north-south arterials in the six zones, however. This is due to the rerouting of trips to north-south arterials to gain entry to the expressway.

The entire Village of Oak Park (zones 2, 5, and 8) had a reduction in travel on arterials. The absence of expressway ramps at Ridgeland and Oak Park Avenues held traffic volume almost equal on these arterials from 1959 to 1961. These two arterials did not

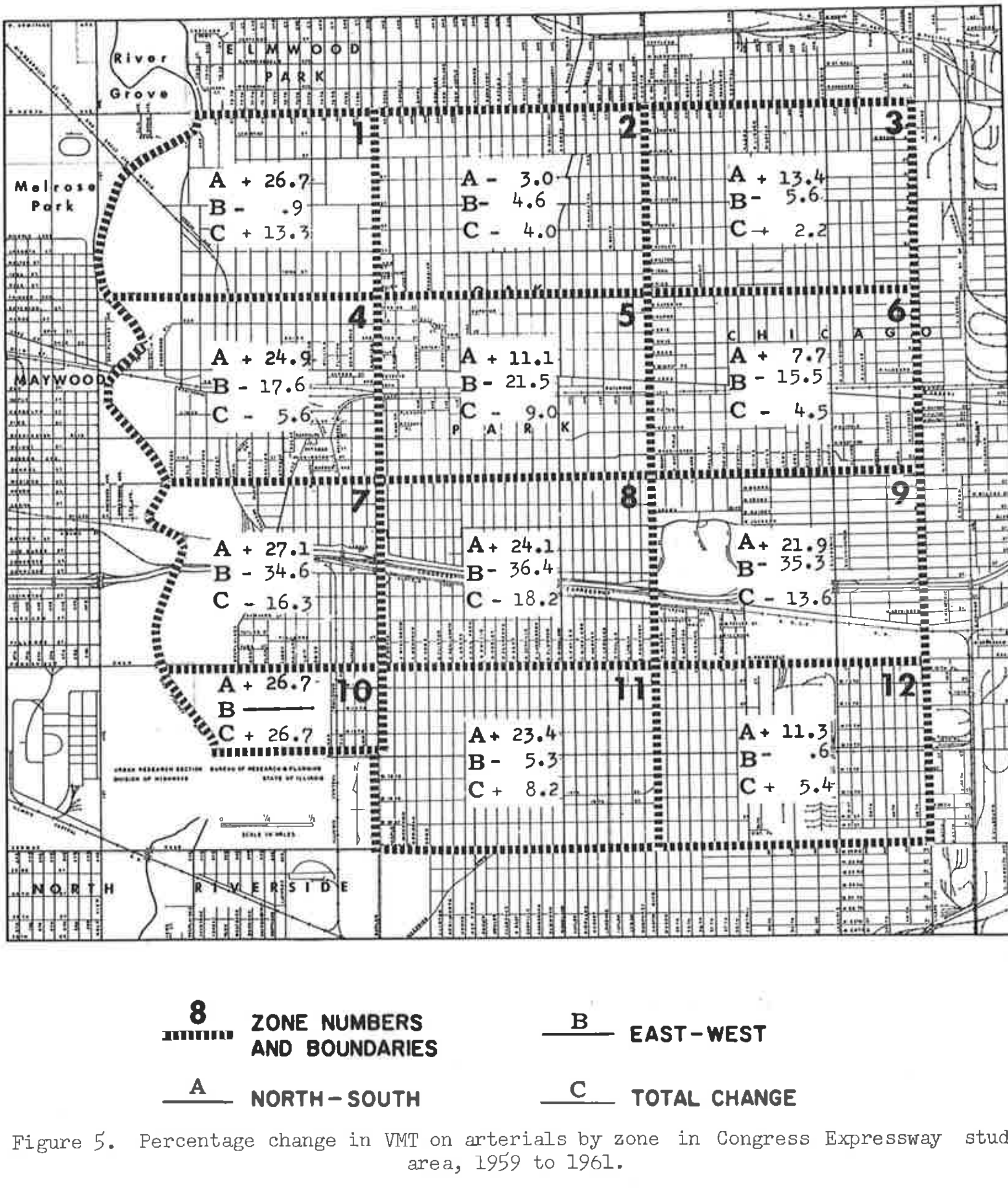


Figure 5. Percentage change in VMT on arterials by zone in Congress Expressway study area, 1959 to 1961.

experience a natural growth increase because of a shifting of traffic to Austin Boulevard and Harlem Avenue to interchange with the expressway. Before the opening of the expressway, Oak Park arterials were carrying a heavy volume of east-west traffic. A portion of this traffic on Roosevelt Road, Jackson Boulevard, Madison Street, Washington Boulevard, Lake Street, Chicago Avenue, Augusta Boulevard, and Division Street has been transferred to the expressway. It was assumed that the congested condition of the arterials in this area was encouraging drivers to use local streets rather than arterials. An examination of the ADT on local streets in 1959 and 1961 shows this to have been a valid assumption. The ADT for all local streets in Oak Park dropped from 1,330 to 1,100 from 1959 to 1961.

The zones more distant from the expressway increased in arterial traffic at a rate

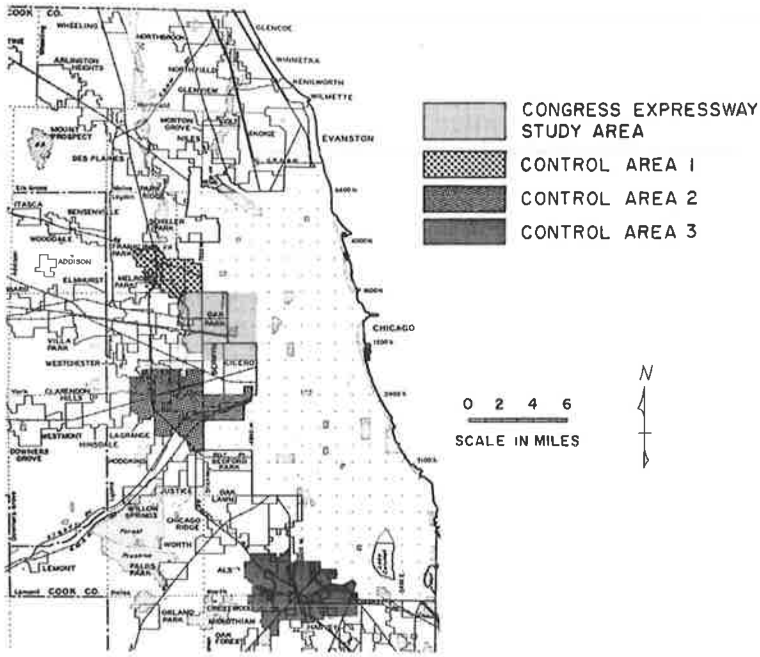


Figure 6. Congress Expressway study area and three selected control areas.

equal to the expected natural growth of 7 percent. However, the traffic within these zones was rearranged; that is, there was a decrease in east-west travel, and an increase in north-south travel. This indicates that these zones were also influenced by the expressway, and that the increases were not the result of natural growth alone.

TRAFFIC VOLUME IN SELECTED CONTROL AREAS

In addition to the study area, three control areas were selected for measuring the change in traffic volume between 1959 and 1961 (Fig. 6). The purpose of counting in the control areas was to establish the overall two-year traffic volume growth. This overall growth is compared to the increase in accidents from 1959 to 1961. No detailed breakdown of traffic distribution in the control areas is made.

Spot check counts made in the control areas during October 1961 indicated an increase in traffic of 19 percent. The counts in the control areas represent a small sample and can only be considered as indicating a sizable increase in traffic. A detailed study of growth trends in the CATS area indicates an increase in traffic in the control areas of 7.0 percent per year, or 14.0 percent for a two-year period. The exact amount of increase is not important, except that there was a somewhat similar increase in the control areas as in the study area.

SUMMARY AND CONCLUSIONS OF TRAFFIC VOLUME MEASUREMENTS

The rearrangement of traffic in the study area has been determined. A portion of the traffic on the local and arterial street systems has been transferred to a higher class of facility; that is, local to arterial or expressway, and arterial to expressway. As a result, there has been a shift of the congestion problem from the east-west to the north-south arterials.

In addition to the rearrangement of traffic, an increase in total VMT, greater than natural growth, has been observed. There is evidence that traffic has been diverted through the area. Long-distance trips, which previously used routes outside the expressway corridor, now find it advantageous to use the expressway.

TABLE 4

MOTOR-VEHICLE TRAFFIC ACCIDENTS DURING 1959 AND 1961 IN STUDY AREA AND THREE CONTROL AREAS

Area	Accidents by Severity Class							
	Fatal		Personal Injury		Property Damage Only		Total	
	1959	1961	1959	1961	1959	1961	1959	1961
Control 1	1	8	363	463	703	791	1,067	1,262
Control 2	2	4	403	430	847	846	1,252	1,280
Control 3	8	6	431	618	897	1,011	1,336	1,635
All control areas	11	18	1,197	1,511	2,447	2,648	3,655	4,177
Congress Expressway study area	10	10	1,616	1,562	5,004	4,492	6,630	6,064

Three control areas in which no expressway exists were chosen. The increase in VMT in these areas was estimated and compared to the increase in the study area. If traffic alone determines the number of accidents in an area, the study area should have experienced a greater increase in accidents than the control areas. The difference in the accident experience will be a measure of the effectiveness of an expressway in reducing accidents.

TABLE 5

CHANGE IN TRAFFIC VOLUME AND ACCIDENT EXPERIENCE IN STUDY AREA AND CONTROL AREAS FROM 1959 TO 1961

Characteristic	Change (%)	
	Congress Area	Control Areas
Traffic	+21.0	+14.0
Accidents:		
Fatal	0	+63.6
Personal injury	- 3.3	+26.2
Property damage only	-10.2	+ 8.2
Total	- 8.5	+14.3

TRAFFIC VOLUME—ACCIDENT RELATIONSHIP

Comparison of Study Area and Three Control Areas

The effect of the expressway on accident experience is measured by comparing changes in the study area with changes in three control areas in which no expressway construction had taken place (Fig. 6). Comparable before and after study periods were chosen, and traffic and accident data were obtained.

Data obtained from the Division of Highways, State of Illinois, show that the study and control areas had dissimilar changes in the number of accidents from 1959 to 1961. Whereas the total number of accidents in the control areas rose more than 14 percent, that in the study area dropped more than 8 percent. A breakdown by area and severity is given in Table 4.

A comparison of the changes in traffic volume and accident experience in the study area and the three control areas is given in Table 5.

The expressway is the one major difference between the study area and the control areas which could have caused such a dissimilar reaction in accident occurrence. The expressway carries 100,000 vehicles per day at an accident rate one-third that of an arterial (2). In addition to carrying vehicles at a lower accident rate, the expressway reduces congestion on arterial and local streets in the surrounding area, and reduces their accident rate.

TABLE 6

ACCIDENT RATES BY STREET TYPE IN STUDY AREA IN 1959 AND 1961

Street Type	Total Accidents per Million Vehicle-Miles of Travel		Change in Accident Rate 1959 to 1961 (%)
	1959	1961	
Local	22.9	21.6	- 5.7
Arterial	9.7	8.8	- 9.3
Expressway	3.6[a]	2.0	— a
Total	12.3	9.3	-24.4

[a]There was ½ mi of expressway in 1959 which functioned more as a long ramp to the western terminus at Laramie Avenue.

TABLE 7

ACCIDENTS ON ARTERIAL STREETS BEFORE AND AFTER OPENING THE EXPRESSWAY (TWO COMPARABLE FOUR-MONTH PERIODS)

North-South Arterials	Total Number Accidents			East-West Arterials	Total Number Accidents		
	Before	After	Change		Before	After	Change
Cicero	202	212	+10	Cermak	125	113	- 12
Laramie	135	118	-17	16th	52	46	- 6
Central	106	93	-13	Roosevelt	131	66	- 65
Austin	80	85	+ 5	Jackson	57	37	- 20
Ridgeland	46	44	- 2	Madison	123	105	- 18
Oak Park	56	44	-12	Washington	84	61	- 23
Harlem	90	106	+16	Lake	116	104	- 12
Des Plaines	18	18	0	Chicago	110	78	- 32
Lathrop	15	18	+ 3	Augusta	46	41	- 5
Thatcher	15	9	- 6	Division	42	41	- 1
Total	763	747	-16	Total	886	692	-194

Having compared the study area with the control areas and discovered the overall beneficial effects of an expressway, detailed accident data collected to represent the study area will be related to traffic volume in the form of accident rates for further analysis.

Accident Rates in the Study Area

The increase in traffic and decrease in accidents in the study area between 1959 and 1961 have been mentioned. In the succeeding paragraphs, traffic volume is converted into VMT and related to traffic accidents in the form of accident rates. These rates are determined by street type for 1959 and 1961. If accidents are related directly to traffic, the accident rate for the area (all streets), and for each street type, will remain the same.

The daily traffic volume is converted into VMT and factored by 339.5 (the average weekend day or holiday volume has been determined to be 77 percent of the average weekday volume; the resultant factor equals 339.5) to represent a year. Yearly VMT are divided into the total annual traffic accidents to determine the accident rates by street type. These rates are given in Table 6 for 1959 and 1961.

The accident rate for the entire area, and for each street type, was reduced. Ordinarily, if an increase in traffic of 21 percent were forced into an area, the accident rate would increase. However, with the introduction of an express facility, the 21 percent traffic increase was absorbed, traffic congestion on local and arterial streets was relieved, and the accident rate for the area was reduced 25 percent.

Accidents on North-South and East-West Arterial Streets

The traffic volume on east-west arterials decreased and the volume on north-south arterials increased. This shift in traffic volume results in a similar shift in the location of traffic accidents. Every east-west arterial with the exception of Division Street and North Avenue (the two most distant arterials from the expressway) had decreases of 10 percent or more in total accidents.

Except for Central Avenue, the north-south arterials experienced expected changes in the total number of accidents. Cicero Avenue, Austin Boulevard, Harlem Avenue, and Lathrop Avenue increased in number of accidents; Laramie Avenue, which had formerly served as the western terminus of the expressway, decreased. Laramie Avenue also had a substantial decrease in congestion in the area of the expressway. Ridgeland and Oak Park Avenues in the Village of Oak Park do not have expressway ramps, and had little change in accident experience. Central Avenue had a large increase in traffic, but also a decrease in accidents. This may be due to changes in parking restrictions, turning restrictions, and signal timing, or to chance. The overall pattern, however, reflects the relationship between traffic and accidents, and the change in accident locations closely resembles anticipated results.

A comparison of Figures 2 and 7 shows the relationship between traffic volume and traffic accidents from 1959 to 1961. Unfortunately, the limited number of cases (accidents) for each arterial makes it impossible to compute meaningful accident rates. Over a period of time, however, the accident rate would be expected to reflect the traffic volume-to-design capacity ratio of all arterial streets in the area.

The absolute change in the total number of traffic accidents on arterials in the study area is given in Table 7. These figures are for two comparable four-month periods; that is, November 1959 through February 1960, and November 1960 through February 1961. North Avenue is omitted from the table because a complete enumeration of accidents was not assured.

As expected, reducing traffic on east-west arterials reduced the total number of accidents on these streets. Although not as definite, the increased traffic volume on north-south arterials appears to have caused an increase in traffic accidents on these streets. Three of the four north-south arterials with expressway ramps (Cicero, Austin, and Harlem) had increases in the number of accidents. The exact reason for the decrease in accidents on Central Avenue is unknown.

ACCIDENT COST SAVINGS

The significant drop in the accident rate in the study area from 1959 to 1961 can be translated into dollar savings by computing the accident cost per VMT in 1959, applying this rate to the VMT in 1961, and then subtracting the known cost (number of accidents in 1961 times the average cost per accident) from the calculated cost (1961 VMT times the accident cost rate per mile traveled).

The average cost of an accident was obtained from the Illinois Motor Vehicle Accident Cost Study (8) conducted in 1958. Because the average cost of an accident may differ in the Chicago area from the remainder of the State, the average costs in Table 8 refer only to accidents that occurred in urban areas with over 50,000 population in Cook and Du Page Counties.

The total accident cost for the study area is determined by multiplying the number of accidents (by severity class) by the corresponding average cost per accident, and

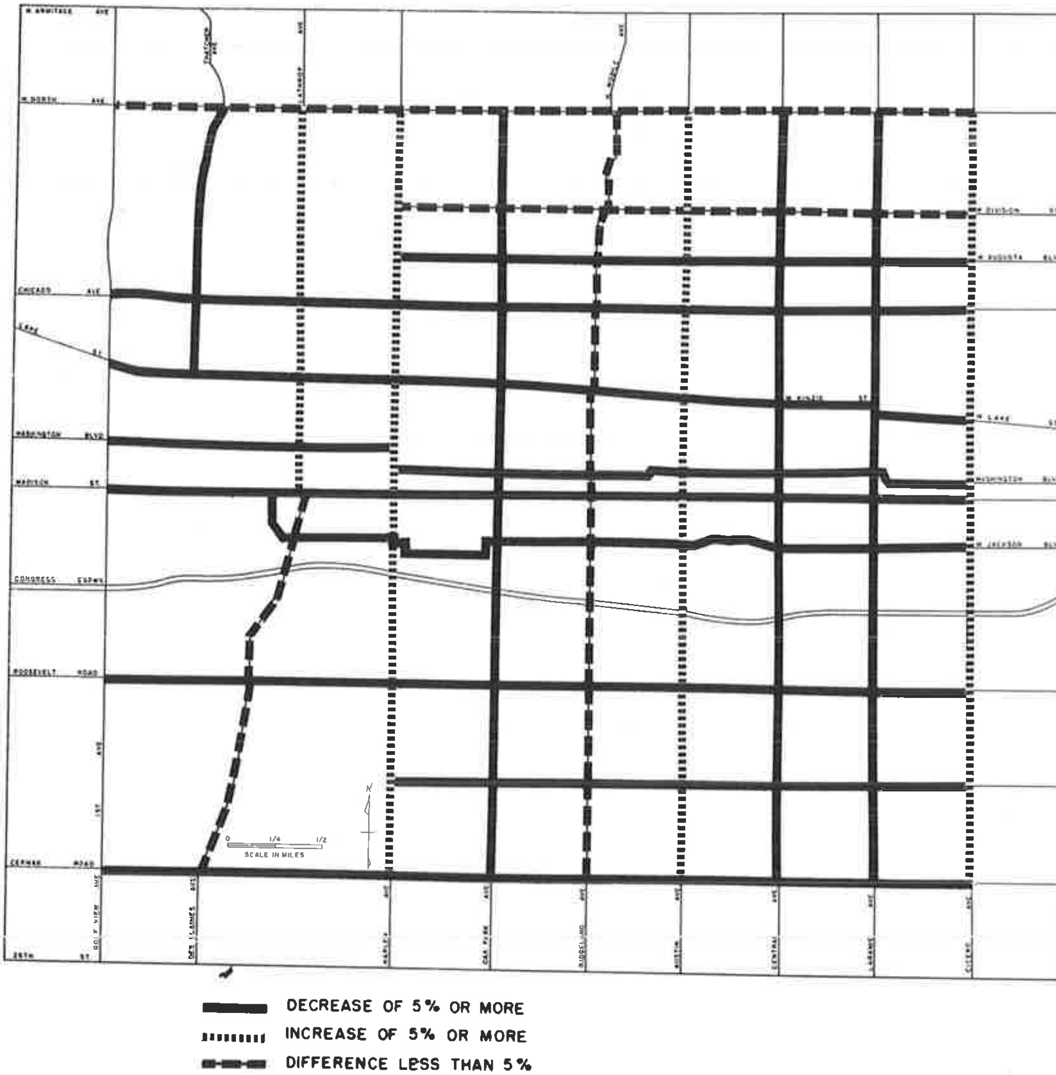


Figure 7. Change in total number of reported accidents in Congress Expressway study area for all arterial streets, 1959 to 1961.

summing the results (Table 9). The total cost then is divided by the total VMT to obtain an accident cost rate:

$$\text{Accident cost rate} = \frac{\text{Total accident cost}}{\text{Total VMT}}$$

The accident cost rate in the area in 1959 is $3,853,220 ÷ 539,126,000 = $0.07 per VMT. This is the reported accident cost of traveling one mile in the study area without an expressway.

Before the accident cost rate can be applied to the 1961 VMT, induced and adverse travel must be subtracted from the 1961 total. Without the construction of the expressway, neither induced nor adverse travel would be driven. Diverted travel, on the other hand, consists of travel which would be driven in another area if the expressway had not been constructed. Natural growth in VMT for the two-year period should be included in determining the total accident cost in 1961 without expressway construction.

TABLE 8

AVERAGE COST OF REPORTED MOTOR-VEHICLE TRAFFIC ACCIDENTS IN CHICAGO AREA IN 1958

Accident Type	No. of Accidents	Accident Cost ($)	Average Accident Cost ($)
Fatal	242	868,061	3,590
Personal injury	27,109	44,622,406	1,650
Property damage only	77,992	17,768,267	230
Total	105,343	63,258,734	600

TABLE 9

COST OF REPORTED MOTOR-VEHICLE TRAFFIC ACCIDENTS IN 1959

Accident Type	No. of Accidents	Average Cost ($)	Total Cost of Accidents ($)
Fatal	10	3,590	35,900
Personal injury	1,616	1,650	2,666,400
Property damage only	5,004	230	1,150,920
Total	6,630	—	3,853,220

The total VMT in the study area in 1961 was 652,519,000. A detailed discussion of the number of VMT that should be attributed to inducement and adverse travel can be found in a separate report (4). When induced and adverse travel is subtracted, 625,925,000 is considered the number of miles which would have been driven in 1961 regardless of whether the expressway was constructed. The accident cost rate per VMT in 1959 is applied to the 1961 VMT and a total accident cost of $4,381,000 is determined.

The total 1961 accident cost for a situation with the expressway open is determined by applying the average cost of an accident by severity type to the known accident totals (Table 10).

The difference between the total 1961 accident cost with an expressway open is subtracted from the total 1961 accident cost without an expressway to determine the dollar savings. During 1961, the savings in the study area were $735,000 or $210,000 for each mile of expressway opened for use:

Total accident cost without expressway	$4,381,000
Total accident cost with expressway	-3,646,000
Savings in accident cost	$ 735,000

An original estimate of accident cost savings attributable to expressway construction was made by Hoch (1), comparing accident experience on arterials and expressways. An estimate of $167,000 per year per mile of expressway constructed was made.

TABLE 10

COST OF REPORTED MOTOR-VEHICLE TRAFFIC ACCIDENTS IN 1961

Accident Type	No. of Accidents	Average Cost ($)	Accident Cost ($)
Fatal	10	3,590	35,900
Personal injury	1,562	1,650	2,577,300
Personal damage only	4,492	230	1,033,160
Total	6,064	—	3,646,360

Hoch's estimate was based on the accident cost per 100,000 mi on an expressway as compared to an arterial. This comparison did not consider adverse travel, the effect of the reduction of congestion on arterials, changes in origin and destinations, or changes in local street usage. (Hoch accounted for these variables through a list of qualifying remarks. Data were not available to measure these effects.) By studying an area, it was possible to measure these effects and incorporate them in this accident cost-saving estimate.

CONCLUSIONS

Traffic in the east-west corridor, which connects the downtown Chicago area and the expanding western suburbs, has increased greatly over the past fifteen years. Chicago and its satellitic suburbs of Oak Park, Berwyn, and Cicero were well-established communities fifteen years ago and the street system which existed in 1947 could have safely and efficiently handled the traffic demands of the area if two circumstances had not occurred—an increase in automobile ownership and a tremendous growth in suburban living.

As the population of the western suburbs continued to grow, the east-west arterial streets leading to the CBD became increasingly congested. This congestion resulted in low average speeds and safety hazards. Long-distance through trips made their way down crowded arterial streets and filtered through residential streets to avoid traffic jams at intersections. It became apparent that an express facility was necessary to alleviate the congestion on the street system in the corridor.

Just how successful the expressway has been could not be conclusively stated. However, as each additional length of the expressway was opened, a noticeable drop in traffic on east-west arterials was observed. From 1955 to 1958, accidents on Chicago Park District drives which parallel the expressways were reduced as much as 40 percent. The east-west corridor (between North Avenue and Cermak Road) from the CBD to the western terminus of the expressway had a smaller proportion of the total accidents in Chicago in 1959 than in 1955. This decrease in accidents occurred even though traffic volume in the corridor was increasing. The indication was that an expressway could effectively relieve traffic congestion and reduce traffic accidents. This report summarizes the results of a test of the beneficial effects of the expressway on a 16-sq mi area.

The rearrangement of traffic and shift of motor vehicles to the expressway resulted in a 25 percent reduction in the accident rate within the study area. There are fringe benefits to the north and south of the study area, but the major benefits accrue to the area in close proximity to the expressway.

When traffic congestion was relieved on arterial streets in the area, the arterial accident rate was reduced. The number of accidents was reduced more than the number of VMT. This implies that the expressway not only carries vehicles at a lower accident rate but also makes the arterials in the area safer for the vehicles that are not transferred to the expressway.

In the two-year period from 1959 to 1961 there was a 7 percent reduction in the VMT on local streets. Because the computation of VMT on local streets is based on a sample of local street segments, a change of 7 percent cannot be considered significant. However, on several local street segments where direct comparisons of 1959 and 1961 figures were possible, reductions as high as 15 percent were observed. Also, the total number of accidents on local streets dropped more than 8 percent from 1959 to 1961. It appears reasonable to assume that a portion of local street travel (through trips) was transferred to arterial streets. This is a desirable process, inasmuch as arterial street's accident rate is one-half that of the local street.

If accident rates were constant, regardless of street type and amount of congestion on the street system, the 1961 total number of accidents in the study area, based on 1961 VMT, would have been higher by 1958 than the actual totals. This total consists of three fatal, 392 personal injury, and 1,563 property damage only accidents. However, the opening of an express facility enabled motorists to travel at a lower accident rate on the expressway, and lessened the danger of travel on arterial and local streets in the area.

The experiences of three control areas examined concurrently with the study area are examples of the result of increasing traffic volume without improving the traffic-carrying ability of the street system. In these three control areas, a 14 percent increase in traffic resulted in a 14 percent increase in accidents. This is particularly alarming because of large increases in fatal (from 10 to 18) and personal injury (from 1,197 to 1,511) accidents. The study area would have experienced somewhat similar increases if the expressway had not been constructed.

The dollar saving in accident cost, due to the expressway in the area studied, is estimated at over $700,000 during the first year of operation. This amounts to $200,000 per year per mile of expressway opened to the public. This is an estimate of the savings in the direct cost of reported accidents. Additional dollar savings in unreported accidents would also be expected. The $200,000 figure is based on the total VMT minus adverse travel and induced traffic; that is, only traffic that would have been driven in 1961 regardless of whether an expressway was constructed.

The redistribution of traffic volume on the arterial network, as a result of the expressway, caused some new problems in the area, however. North-south arterials with expressway interchanges experienced large increases in traffic volume and accompanying increases in accidents. The traffic volume on Cicero, Austin, and Harlem Avenues increased to a point where it exceeded the design capacity of the street. A portion of this traffic proceeds from the expressway interchange to points north and south of the study area.

The construction of express facilities has been recognized as an efficient and safe means of carrying large volumes of traffic. This paper summarizes the results of a test of the effectiveness of an expressway in benefiting an area in terms of reducing congestion, accidents, and accident costs.

REFERENCES

1. Hoch, I., "Accident Experience: Expressways vs Arterials." Chicago Area Transportation Study (1959).
2. Frye, F. F., "Accident Rates by Street Type." Chicago Area Transportation Study (1961).
3. "The Effect of an Expressway on an Area—Accidents." CATS Research News, Vol. 4, No. 3 (Dec. 1, 1961).
4. Frye, F. F., "Expressways: Traffic and Accidents." Chicago Area Transportation Study (July 1962).
5. "An Appraisal of Traffic Circulation in Oak Park, Illinois." Barton-Aschman Assoc. (Feb. 27, 1960).
6. Wallen, W. A., "Landscaped Structures for Traffic Control." Traffic Engineering (Jan. 1961).
7. Marks, H., "Subdividing for Traffic Safety." Traffic Quart. (July 1957).
8. Illinois Motor-Vehicle Accident Cost Study, Division of Highways, State of Illinois (Dec. 1962).

Effect of Northwest Expressway on Alternate Arterial Streets

MATTHEW C. SIELSKI, Director, Safety and Traffic Engineering Department, Chicago Motor Club, Chicago, Illinois

AT THE Sagamore Conference on Highways and Urban Development (1), the following observation was made:

> In order to properly locate new highways in existing urban areas, we need to know more about the highways' effect on the area and the area's effect on highway design and location requirements.

Bacon (2) states that the objective of a metropolitan highway system is to aid in the movement of people and goods within a metropolitan area with maximum economy, efficiency, and dispatch. An analysis of the benefits of an expressway, therefore, should include the before and after traffic characteristics on all major streets in the area of the new highway. Generally, planning engineers compute savings in time, fuel, and accidents on expressways and do not analyze benefits derived by vehicles remaining on old routes after traffic is diverted to the expressway.

This study includes before and after comparisons of travel time, fuel consumption, accidents, and other factors relating to highway benefits on major arterial streets serving as alternate routes to the new Northwest Expressway in Chicago. It is the purpose of the study to determine if there are any additional benefits to motorists using these alternate routes. Such information should be considered in the development of feasibility studies made in conjunction with contemplated expressways.

Because time and fuel saving are two of the most important benefits that accrue to users through highway improvement, much study has been devoted to them. Experience has shown that wherever stop-and-go maneuvers are reduced, the amount of fuel saving is quite noticeable (3). This benefit can be fairly accurately calculated. The amount of time motorists save on one facility as compared to another is difficult to measure in relation to monetary savings. However, despite the absence of reference to monetary saving, this report does seek the actual time saved with the thought that such information could be used for analytical purposes.

DESCRIPTION OF PROJECT STUDY

Northwest Expressway

The Northwest Expressway was opened to traffic November 5, 1960. It is part of Chicago's comprehensive system of radial highways. From its junction with Congress Expressway at the Halsted Interchange, it spans 16 miles of the city to link the central business district (CBD) with the Northwest suburbs and O'Hare International Airport (Fig. 1). Its first junction is with Edens Expressway and later the Northwest Tollway.

Between downtown and Edens Expressway, it consists of four lanes in each direction, separated by two additional lanes which are used for reversible lane movements during the rush hours. This portion of the expressway carries approximately 160,000 vehicles per day (4).

Alternate Routes

This study could not undertake a detailed analysis of all major arteries affected by

Presented at January 1963 Business Meeting of Committee on Speed Characteristics.

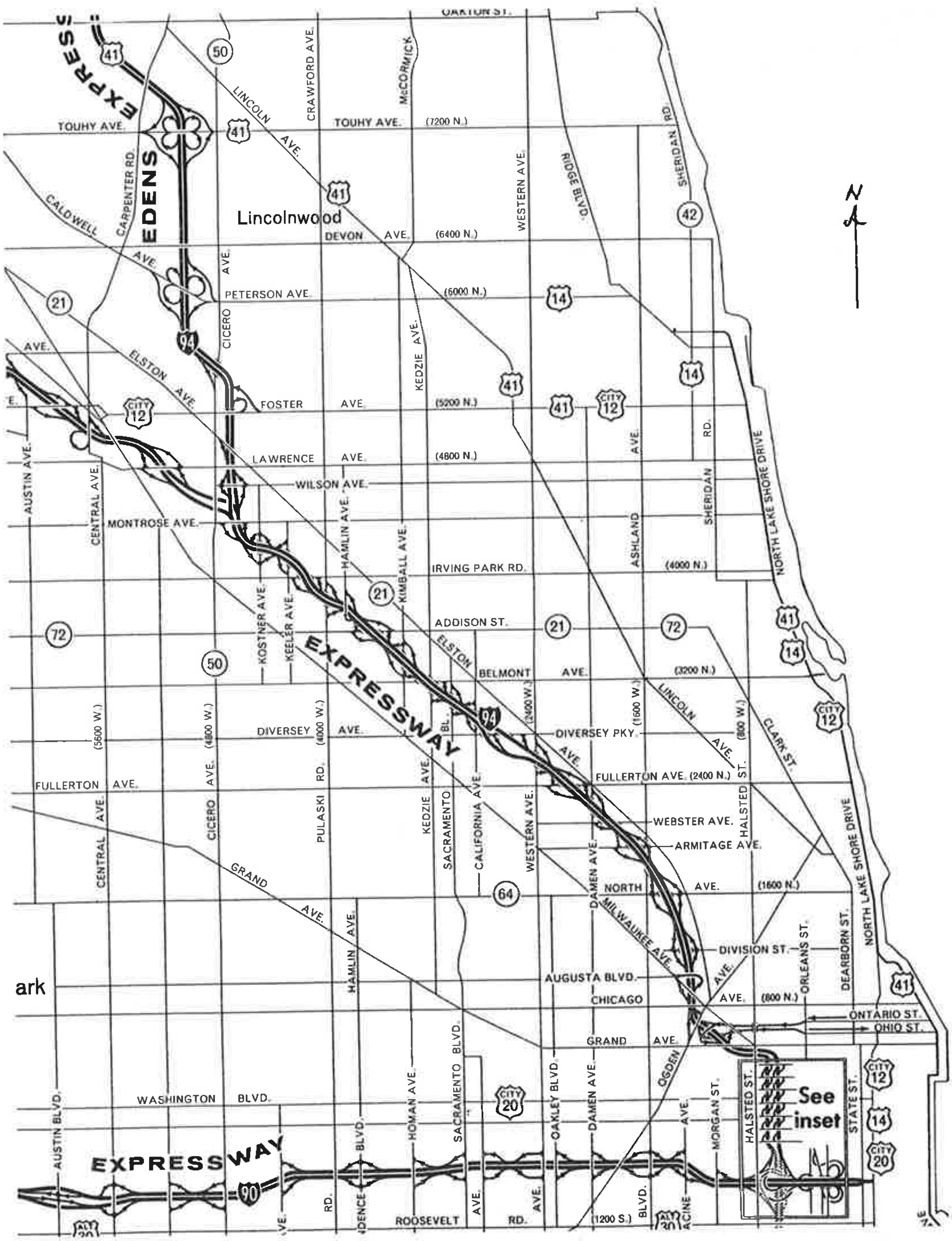


Figure 1. Study area.

the Northwest Expressway. Therefore, several important streets were selected as typical examples. For a more realistic comparison, several arteries were grouped to represent typical routes followed by motorists from the northwest side of Chicago to the CBD. The information derived from these data was used as a basis for all routes influenced by the Northwest Expressway. The study routes are described as follows:

Route 1.—This route starts at the intersection of Cicero and Lincoln Avenue in Skokie and terminates in the CBD at Lake Shore and Ohio (Fig. 2). Its various sections are as follows:

Street	Section	No. of Miles
Lincoln Avenue	Cicero to Peterson	3.3
Peterson-Ridge-Hollywood	Lincoln to Sheridan Rd.	3.5
Lake Shore Drive	Hollywood to Ohio	7.3
	Total	14.1

Route 2.—This route beginning at Foster and Cicero was used for travel to the CBD:

Street	Section	No. of Miles
Foster Ave.	Cicero to Lincoln	3.0
Foster Ave.	Lincoln to Lake Shore Dr.	2.1
Lake Shore Dr.	Foster to Ohio	6.4
	Total	11.5

Route 3.—This route closely parallels the Northwest Expressway for almost its entire length. It was studied from Cicero on the north to North Avenue at the south for 6.9 mi. It does not terminate at the CBD but is part of a typical route to that area.

Summary

The analysis of this report covered a total of 32.5 mi of arterial streets, including Lake Shore Drive from Hollywood. The following studies were made on these routes before and after the opening of the Northwest Expressway:

1. Gas consumption.
2. Travel time.
3. Traffic volume.
4. Accident experience.

GAS CONSUMPTION

One of the major factors which measures the economy of a street system is the fuel consumption performance of a vehicle. Many studies have been made showing the relationship between frequent start-and-stop operations and fuel performance. Although overall speeds are increased where stop-and-go operations are reduced, the fuel saved from constant acceleration, idling, and deceleration surpasses the increased consumption due to speed (3).

Careful measurements were made of fuel consumption performance under similar conditions before and after the opening of the expressway. Each of the three routes were frequently traveled by a 1958 Chevrolet. The amount of gasoline consumed in each run was measured by a Vacumat gasoline mileage tester. In this device, the main gas source is disconnected and fed through a $\frac{1}{10}$-gal glass burette mounted on the inside door of the vehicle. The operator can easily measure the amount of fuel consumed in relation to distance traveled. The instrument used in this study is shown in Figure 3.

Tables 1 and 2 give the results of all the gas tests.

Datail of Gas Consumption Study

Details of the gas consumption study are given in Table 3.

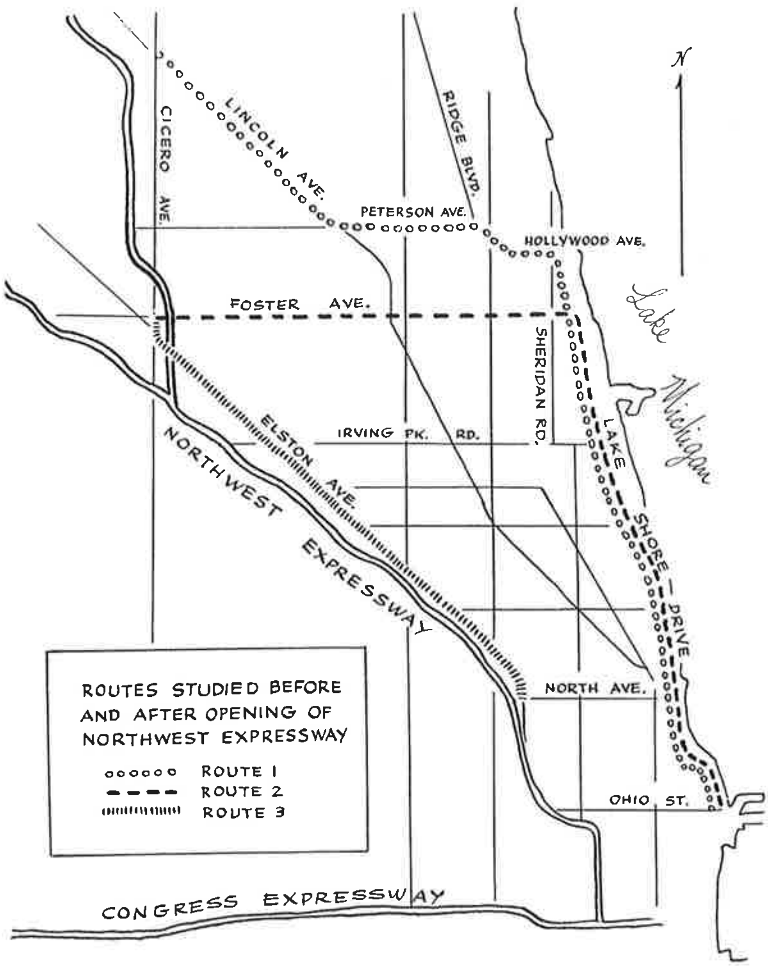


Figure 2. Routes studied before and after opening of Northwest Expressway.

Summary of Study

1. Average miles per gallon on arterial streets before expressway = 13.2
2. Average miles per gallon on arterial streets after expressway = 15.9
3. Average saving in gas in gallons per mile on arterial streets after expressway = 0.013
4. Average miles per gallon on Lake Shore Drive before expressway = 17.0
5. Average miles per gallon on Lake Shore Drive after expressway = 21.0
6. Average saving in gas in gallons per mile on Lake Shore Drive after expressway = 0.011

TRAFFIC VOLUME STUDY

Twelve-hour volume counts were made available by the Traffic Engineering Division of the City of Chicago for the various routes studied in this report. Table 4 summarizes counts on routes before and after the opening of the Northwest Expressway.

In the table, traffic volumes for route 1 show the decrease in volume after the opening of the expressway. The major arterial route, discounting Lake Shore comparisons, averaged 26,390 vehicles during a 12-hr period before the expressway, and 20,673 after. This represents a 26.6 percent reduction in traffic. On Lake Shore Drive, the reduction

TABLE 1

SUMMARY OF GAS CONSUMPTION STUDY BEFORE OPENING OF NORTHWEST EXPRESSWAY

Route	Date	Rush Period	Street	Section	Miles Studied	Gas Used Amount (gal)	Gas Used Miles per Gal
1	10/24/60	AM	Lincoln	Cicero-Peterson	3.0	0.20	
	10/24/60	AM	Peterson	Lincoln-Sheridan	3.1	0.21	
	10/24/60	PM	Peterson	Lincoln-Sheridan	3.1	0.19	
	10/24/60	PM	Lincoln	Peterson-Cicero	3.0	0.20	
	Subtotal				12.2	0.80	15.3
2	10/25/60	AM	Foster	Lincoln-Sheridan	2.4	0.15	
	10/27/60	AM	Foster	Cicero-Sheridan	5.5	0.33	
	10/25/60	PM	Foster	Sheridan-Lincoln	2.2	0.21	
	10/24/60	PM	Foster	Sheridan-Cicero	5.5	0.43	
	Subtotal				15.6	1.12	13.9
3	10/26/60	AM	Elston	Foster-North	6.9	0.58	
	10/26/60	PM	Elston	Foster-North	6.9	0.65	
	Subtotal				13.8	1.23	11.2
	Total for arterial streets				41.6	3.15	13.2
Lake Shore Drive	10/25/60	AM		Foster-Ohio	6.7	0.40	
	10/27/60	AM		Foster-Ohio	6.6	0.48	
	10/25/60	PM		Ohio-Foster	7.0	0.37	
	10/24/60	PM		Ohio-Foster	6.8	0.34	
	Total				27.1	1.59	17.0

was 17.0 percent. Although the reduction on Lake Shore Drive was not as significant as the arterial streets, nevertheless it can be assumed that the expressway was previously carrying a substantial number of vehicles that traveled a considerable distance to use the Lake Shore expressway. As later illustrated, the 17 percent reduction was impressive in relation to improved speed performance (Fig. 4).

For route 2, volume counts on Foster at Cicero does not reflect the normal experience of traffic changes at that location because the intersection has traffic generated from the expressway. Consequently, for before and after comparisons, the experience at Foster and Ashland is used in this study. The decrease in traffic since the expressway is 27.4 percent (Fig. 5).

The arterial street in route 3 is adjacent to the expressway and its phenomenal decrease in traffic is understandable. Before the expressway, it had an average 12-hr two-way volume of 18,516 as contrasted to a present count of 10,048, or a 45.2 percent decrease. This change in traffic volume is shown in Figure 6.

The combined decrease on the major arterial streets is given in Table 5.

TRAVEL TIME STUDY

Decreased travel times are of great significance to highway users. Not only are they appreciated but also their economic value is as important as such factors as fuel saving, accident reduction, and lower operating costs. In this study, travel times on arterial streets were measured to determine the increased speed made possible by diverting traffic to the expressway. It is an acceptable conclusion that lower traffic volumes produce faster running speeds. This relationship has been established in varying degrees by many researchers (5, 6, 7).

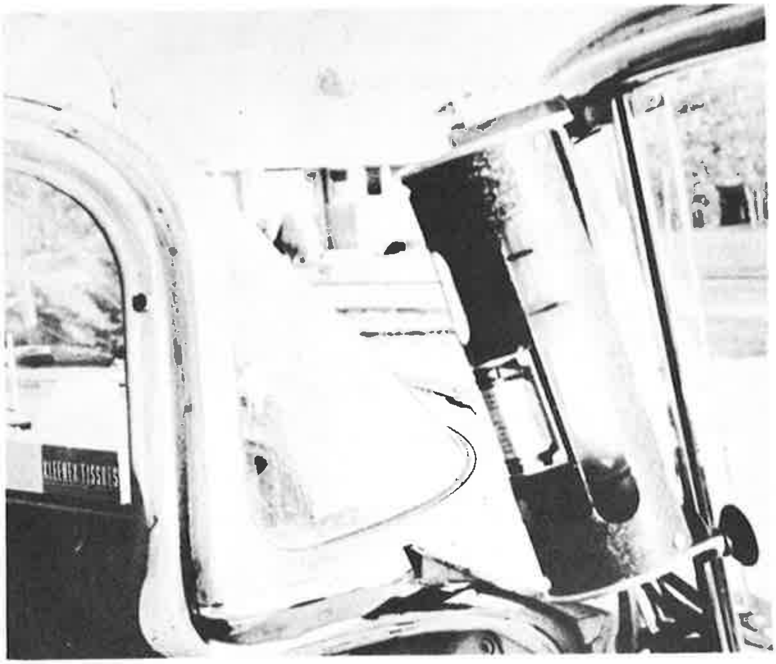


Figure 3. Vacumat gasoline mileage tester.

TABLE 2

SUMMARY OF GAS CONSUMPTION STUDY AFTER OPENING OF NORTHWEST EXPRESSWAY

Route	Date	Rush Period	Street	Section	Miles Studied	Gas Used	
						Amount (gal)	Miles per Gal
1	9/29/61	AM	Lincoln	Cicero-Peterson	3.0	0.18	
	9/29/61	AM	Peterson	Lincoln-Sheridan	3.1	0.18	
	9/27/61	PM	Peterson	Sheridan-Lincoln	3.0	0.18	
	9/27/61	PM	Lincoln	Peterson-Cicero	3.1	0.14	
	Subtotal				12.2	0.68	17.9
2	10/3/61	AM	Foster	Cicero-Sheridan	5.2	0.35	
	9/29/61	AM	Foster	Lincoln-Sheridan	1.4	0.10	
	10/3/61	PM	Foster	Sheridan-Cicero	5.2	0.40	
	Subtotal				11.8	0.85	13.9
3	9/29/61	AM	Elston	Cicero-North	6.8	0.40	
	9/29/61	PM	Elston	North-Cicero	5.5	0.36	
	Subtotal				12.3	0.76	16.2
	Total for arterial streets				36.3	2.29	15.9
Lake Shore Drive	9/29/61	AM		Foster-Ohio	5.5	0.26	
	9/29/61	PM		Ohio-Foster	6.5	0.30	
	10/3/61	PM		Ohio-Foster	7.1	0.35	
	Total				19.1	0.91	21.0

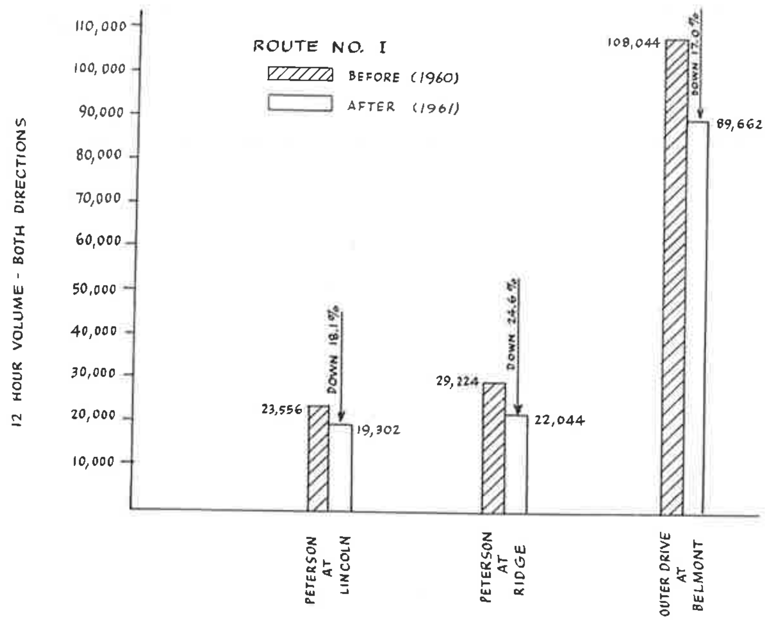


Figure 4. Vehicular volumes before and after opening of Northwest Expressway, Route 1.

To determine the time saving experience on each of the three routes, a series of runs were made before and after the opening of Northwest Expressway. All the studies were made during the two peak periods of the day. A more detailed account of these travel times for each respective route is given in Tables 6 and 7. The monetary value of this time reduction is treated later.

TABLE 3

GAS CONSUMPTION STUDY

Period	Route No.	Miles of Streets Studied	Avg. Gas Consump- tion (gal)	No. of Runs
Before	1	12.2[a]	0.80	4
	2	15.6[a]	1.12	4
	3	13.8	1.23	2
	Lake Shore Dr.	27.1	1.59	4
After	1	12.2[a]	0.68	4
	2	11.8[a]	0.85	3
	3	12.3	0.76	2
	Lake Shore Dr.	19.1	0.91	3

[a]Excluding Lake Shore Drive.

Route 1

The AM peak traffic can traverse the 14.1 mi of route 1 in 8 min 53 sec faster than before the expressway (Fig. 7). In the evening peak, the savings is 7 min 35 sec. The greatest decrease in travel time is reflected in the 5.2 mi of travel on the Lake Shore Drive. This distance can now be negotiated in 9.5 min as against the previous time of 12.5 min, or a savings of 3 min.

Route 2

Figure 8 shows that during the AM peak a vehicle starting on Foster at Cicero can reach Ohio and the Lake Shore Drive 7 min 38 sec faster than before the expressway, and 4 min 50 sec faster in the evening rush. As in Route 1, the greatest travel time decrease occurred on Lake Shore Drive.

Route 3

Elston Avenue (Fig. 9) has had a drastic decrease in travel time, partic-

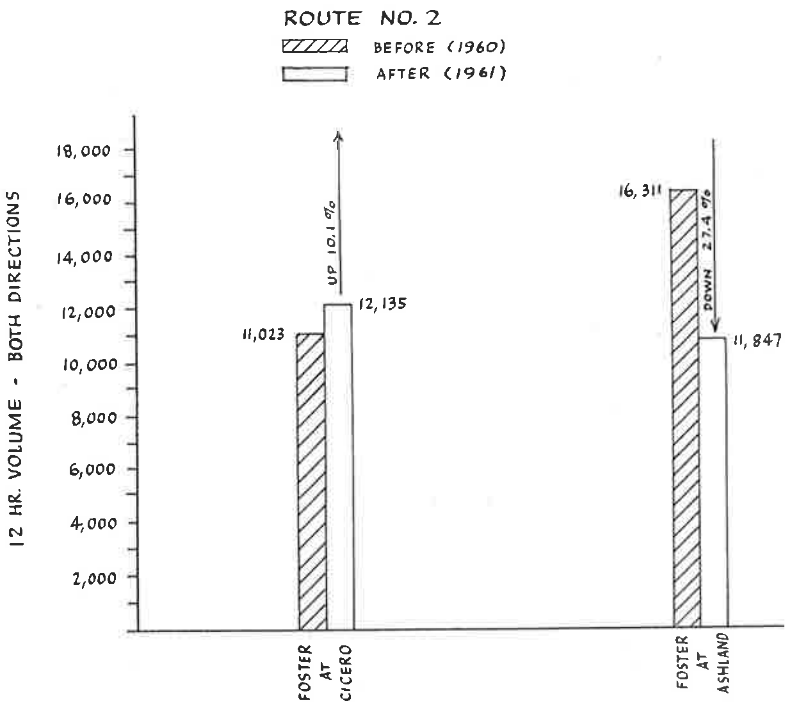


Figure 5. Vehicular volumes before and after opening of Northwest Expressway, Route 2.

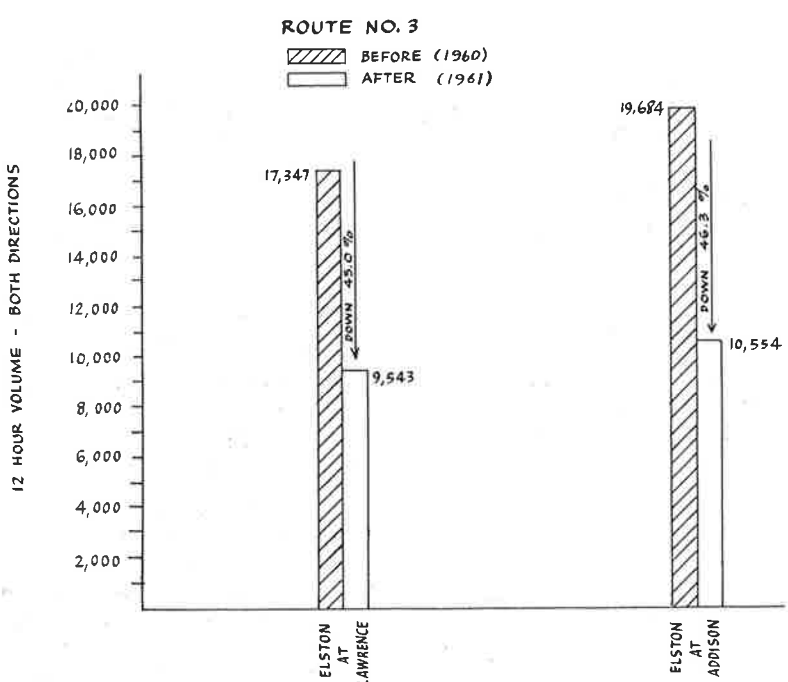


Figure 6. Vehicular volumes before and after opening of Northwest Expressway, Route 3.

TABLE 4

12-HOUR VOLUME COUNTS ON ROUTES BEFORE AND AFTER OPENING OF NORTHWEST EXPRESSWAY

Route No.	Location	Traffic Direction	12-Hr Volume	
			Before	After
1	Peterson at Lincoln	East	10,681	8,863
		West	12,875	10,439
		Two-way	23,556	19,302
	On Ridge at Clark	East	15,433	11,568
		West	13,791	10,476
		Two-way	29,224	22,044
	Lake Shore at Belmont	North	57,627	48,181
		South	50,417	41,481
		Two-way	108,044	89,662
2	On Foster at Cicero	East	5,576	5,740
		West	5,447	6,395
		Two-way	11,023	12,135
	On Foster at Ashland	East	8,602	6,025
		West	7,709	5,822
		Two-way	16,311	11,847
3	On Elston at Lawrence	Northwest	8,981	4,389
		Southeast	8,366	5,154
		Two-way	17,347	9,543
	On Elston at Addison	Northwest	9,392	5,462
		Southeast	10,292	5,092
		Two-way	19,684	10,554

ularly in the PM period. The 6.9 mi of major arterial street that were surveyed after the opening of the expressway, was negotiated in 20 min 5 sec faster on the average, than before the opening of the expressway. During the morning peak, the average decrease in travel time, after the opening of the expressway, was 4 min 57 sec.

Summary of Travel Time

Table 8 gives a summary of the saving in travel time per vehicle per trip experienced on the various major arterial streets in this survey.

TABLE 5

COMBINED DECREASE[1] IN AVERAGE 12-HR TWO-WAY VOLUMES ON MAJOR ARTERIAL STREETS

Route No.	Avg. Volume	
	Before	After
1	26,390	20,673
2	16,311	11,847
3	18,516	10,048
Total	61,217	42,568

[1]Average decrease = 31.5 percent.

The Lake Shore Drive experience is summarized as follows:

Avg. travel time before = 12 min 0.1 sec
Avg. travel time after = 9 min 31 sec
Time saved per mile after Northwest Expressway = 0.5 min

The monetary value of time saved is an important economic factor in highway planning. Many studies have been conducted in which the value of time was assigned a monetary amount. In commercial vehicle operations, it is not too difficult to assign a value to time saved. The time saved can be directly applied to wages (8). However, in private passenger operation, this value is variable, depending on various

TABLE 6

SUMMARY OF TRAVEL TIMES DURING RUSH HOURS ON ALTERNATE ROUTES BEFORE OPENING OF NORTHWEST EXPRESSWAY

Route No.	Rush Period	Route Path From	Route Path To	Date (1960)	Travel Time (min:sec)
1	AM	Lincoln & Cicero	Lincoln & Peterson	10/21	7:10
				10/27	8:00
				10/28	7:31
				10/31	7:39
				Avg.	7:35
			Hollywood & Sheridan	10/21	20:45
				10/27	18:00
				10/28	19:19
				10/31	19:27
				Avg.	19:23
			Lake Shore & Ohio	10/21	33:15
				10/27	33:00
				10/28	33:04
				10/31	33:12
				Avg.	33:08
	PM	Lake Shore & Ohio	Lake Shore & Sheridan	10/24	11:30
				10/25	12:30
				10/29	11:45
				11/3	12:15
				Avg.	12:00
			Lincoln & Peterson	10/24	23:35
				10/25	24:20
				10/29	23:40
				11/3	24:25
				Avg.	24:00
			Lincoln & Cicero	10/24	31:35
				10/25	32:25
				10/29	30:45
				11/3	33:15
				Avg.	32:00
2	AM	Foster & Cicero	Lincoln & Foster	10/20	9:30
				10/22	14:00
				10/25	6:45
				Avg.	10:05
			Sheridan & Foster	10/20	15:00
				10/22	22:30
				10/25	14:15
				Avg.	17:15
			Lake Shore & Ohio	10/20	28:50
				10/22	33:10
				10/25	25:15
				Avg.	29:05
	PM	Lake Shore & Ohio	Foster & Ohio	10/12	8:50
				10/13	10:10
				10/24	9:10
				10/17	9:50
				Avg.	9:30
			Lincoln & Foster	10/12	19:15
				10/13	22:15
				10/24	16:30
				10/17	25:00
				Avg.	20:45
			Cicero & Foster	10/12	27:50
				10/13	30:00
				10/24	25:30
				10/17	32:20
				Avg.	28:55
3	AM	Elston & Cicero	Elston & North	10/26	23:00
				10/21	25:00
				10/12	22:25
				10/14	25:35
				Avg.	24:00
	PM	Elston & North	Elston & Cicero	10/14	35:30
				10/12	38.10
				10/26	42:40
				10/18	31:00
				Avg.	36:50

TABLE 7

SUMMARY OF TRAVEL TIMES DURING RUSH HOURS ON ALTERNATE ROUTES AFTER OPENING OF NORTHWEST EXPRESSWAY

Route No.	Rush Period	Route Path From	Route Path To	Date (1961)	Travel Time
1	AM	Lincoln & Cicero	Lincoln & Peterson	4/3	7:30
				4/27	5:30
				5/9	7:00
				Avg.	6:40
			Hollywood & Sheridan	4/3	15:15
				4/27	13:30
				5/9	14:30
				Avg.	14:25
			Lake Shore & Ohio	4/3	26:00
				4/27	22:30
				5/9	24:15
				Avg.	24:15
	PM	Lake Shore & Ohio	Lake Shore & Sheridan	4/3	9:45
				4/9	10:00
				5/9	9:00
				Avg.	9:35
			Lincoln & Peterson	4/3	18:00
				4/9	20:00
				5/9	16:30
				Avg.	18:10
			Lincoln & Cicero	4/3	24:00
				4/9	26:30
				5/9	23:15
				Avg.	24:35
2	AM	Foster & Cicero	Lincoln & Foster	3/14	7:45
				4/4	6:30
				4/5	6:30
				Avg.	6:53
			Sheridan & Foster	3/14	13:00
				4/4	11:30
				4/5	11:00
				Avg.	11:50
			Lake Shore & Ohio	3/14	22:20
				4/4	21:00
				4/5	21:00
				Avg.	21:27
	PM	Lake Shore & Ohio	Lake Shore & Foster	3/16	10:00
				3/17	9:00
				3/28	9:30
				3/29	10:15
				Avg.	9:41
			Foster & Lincoln	3/16	16:35
				3/17	15:38
				3/28	16:30
				3/29	18:00
				Avg.	16:41
			Foster & Cicero	3/16	24:00
				3/17	23:52
				3/28	24:00
				3/29	24:30
				Avg.	24:05
3	AM	Elston & Cicero	Elston & North	3/14	16:00
				3/15	22:05
				3/16	17:35
				3/17	20:31
				Avg.	19:03
	PM	Elston & North	Elston & Cicero	3/14	17:35
				3/13	16:25
				3/17	16:00
				4/5	17:00
				Avg.	16:45

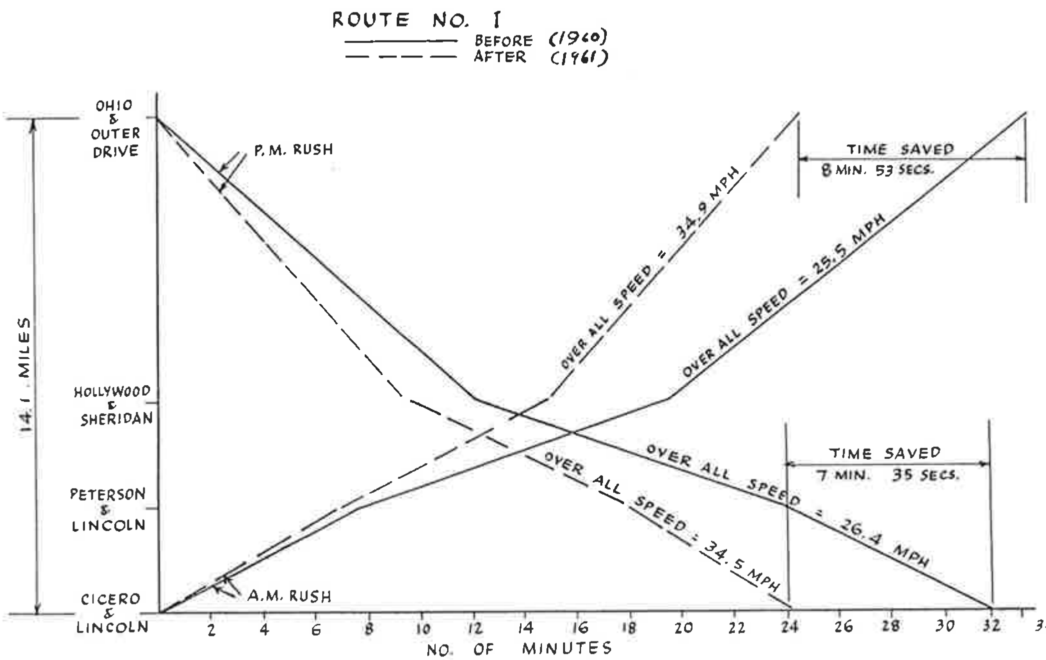


Figure 7. Travel times before and after opening of Northwest Expressway, Route 1.

conditions, day of the week, persons, etc. In the Chicago Area Transportation Study (14, 17), the time costs were given a definite amount:

> The value of time for automobiles was set at $1.17 per hour. This was based upon 75¢ per hour value of passenger time and an average occupancy of 1.56 persons per vehicle. The current Federal minimum wage is $1.00 per hour and no one may work in covered employment for less. Thus, $1.00 per hour per employed person would be a minimum figure. But since some passengers are unemployed, the hourly rate was dropped to 75¢ per hour.

The value of $1.17 per hour was applied to the travel time saved on arterials and North Lake Shore Drive as a result of less traffic.

STUDY OF TRAFFIC ACCIDENTS

An analysis of a highway improvement must include a study of its effect on traffic accidents. Much has been written (15) about the economic value of an expressway in relation to, among other factors, lower accident rates. Very little is known about the accident rate on major arteries influenced by the expressway.

Two studies were undertaken to appraise the effect the Northwest Expressway had on streets in its area. The first study was a general area analysis resembling a similar research project in the area of the Congress Street Expressway

TABLE 8

TRAVEL TIME SAVINGS PER VEHICLE PER TRIP FOR MAJOR ARTERIAL STREETS

Route No.	Length (mi)	Time Saved per Vehicle (min:sec) AM	PM	Avg.
1	14.1	4:58	5:00	4:59
2	5.5	5:25	4:36	5:00.5
3	6.9	4:57	20:05	12:31.5
Total	26.5			22:31
Per mile				0:51

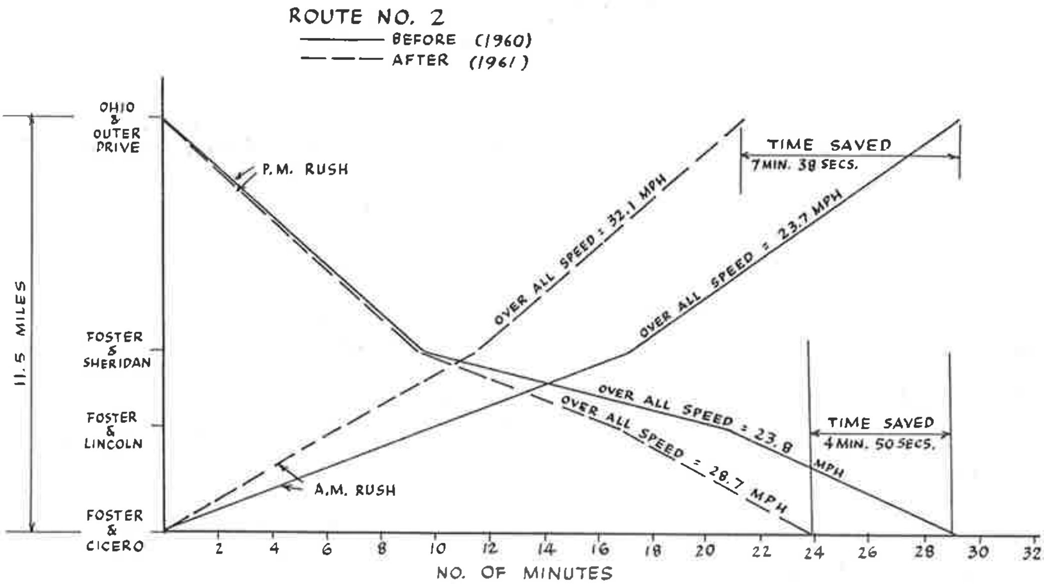


Figure 8. Travel times before and after opening of Northwest Expressway, Route 2.

conducted by the Chicago Area Transportation Study (16). The second study involved an analysis of accidents on the three routes used in other analytical studies in this report.

General Area

Accident data were obtained from the police department for each district adjacent to the Northwest Expressway. The area under surveillance is shown in Figure 10. The accident experience was tabulated for each police district one year before and after the opening of the Northwest Expressway. Table 9 gives this information for each area. Table 10 gives the before and after trend.

This study does not provide significant information for a benefit-cost determination. Perhaps the study included too large an area and consequently did not accurately represent the accident trend. However, total accidents in this study area decreased 1.2 percent, whereas throughout Chicago there was a 3.0 percent increase. This study did not result in the interesting findings made by CATS on Congress Expressway (9). That study revealed an area reduction of 28 percent in fatalities and 14.2 percent in injuries as a result of Congress Expressway.

Major Routes

In this analysis, accurate reports were obtained for every injury and fatal accident recorded on the arterials of each of the three routes. The records included the first six months of 1960 as compared to the first six months of 1961. Property damage accidents were not included for two reasons: (a) inaccuracy of reporting, and (b) difficulty in determining accident costs. This study realizes that there is much to be desired in better information regarding accident costs (10). Therefore, in an effort to minimize inaccuracies, only fatalities and injuries were included for analysis.

Table 11 summarizes the accidents recorded for each section of the three routes observed. There was a 25.8 percent reduction in these accidents for the entire combined arterial street mileage and a 17.0 percent decrease on Lake Shore Drive.

Benefit of Accident Reduction

The method used for determining the economic value of accident reduction is predicated on the accident experience on the three major routes expressed in monetary value

TABLE 9

TRAFFIC ACCIDENTS REPORTED BY POLICE DISTRICTS IN VICINITY OF NORTHWEST EXPRESSWAY

Police Dist.	Total Accidents	Fatal Accidents	Persons Killed	Personal Injury Accidents	Persons Injured	Prop. Dam. Accidents
(a) 1960, Before Northwest Expressway						
32	8,043	20	20	1,594	2,124	6,429
33	5,216	16	16	1,099	1,558	4,101
34	4,697	6	6	928	1,289	3,763
37	2,194	5	5	426	553	1,763
38	5,003	12	13	1,076	1,402	3,915
40	4,509	5	5	821	1,113	3,683
Total	29,662	64	65	5,944	8,039	23,654
(b) 1961, After Opening of Expressway						
32	7,652	12	14	1,545	2,200	6,095
33	5,107	6	6	1,053	1,538	4,048
34	4,993	11	11	943	1,320	4,039
37	2,272	4	4	455	617	1,813
38	4,973	17	17	1,042	1,377	3,914
40	4,318	7	7	821	1,122	3,490
Total	29,315	57	59	5,859	8,174	23,399

per vehicle-mile traveled. This information is then applied to all of the major routes affected by the Northwest Expressway. The computation of this factor is divided into (a) actual monetary saving on three major routes based on known traffic volumes and accidents, and (b) application of this monetary saving to the entire arterial system influenced by the expressway.

Three Major Routes.—As previously indicated, there were 55 fewer accidents reported on the combined street system after the opening of the expressway, of which 10 were on Lake Shore Drive. Table 11 gives the fatal and injury accident experience for the major routes whose travel characteristics were materially changed by the new highway. The volume and number of miles on the three principal routes were converted to total semiannual vehicle-miles traveled (Table 12). In the computation that follows, these data were used to compute the monetary saving resulting from accident reduction.

The determination of the actual cost per accident was based on information obtained from the National Safety Council's Memo 113. The unit cost for the type of accident studied in this project is $1,750 per injury. Because there are 1.43 persons involved in the average injury accident in Chicago, the cost per accident is 1,750 × 1.43 = $2,502.50.

In 1960, the number of accidents per 100 mvm was 204. The total cost of accidents

TABLE 10

TOTAL BEFORE AND AFTER TREND OF ACCIDENT EXPERIENCE

Type of Total	No. Before	No. After	Change (%)
Accidents	29,662	29,315	-1.2
Fatalities	65	59	-9.2
Injuries	8,039	8,174	+1.7
Prop. dam.	23,654	23,339	-1.1
Accidents in Chicago	126,777	129,562	+3.0

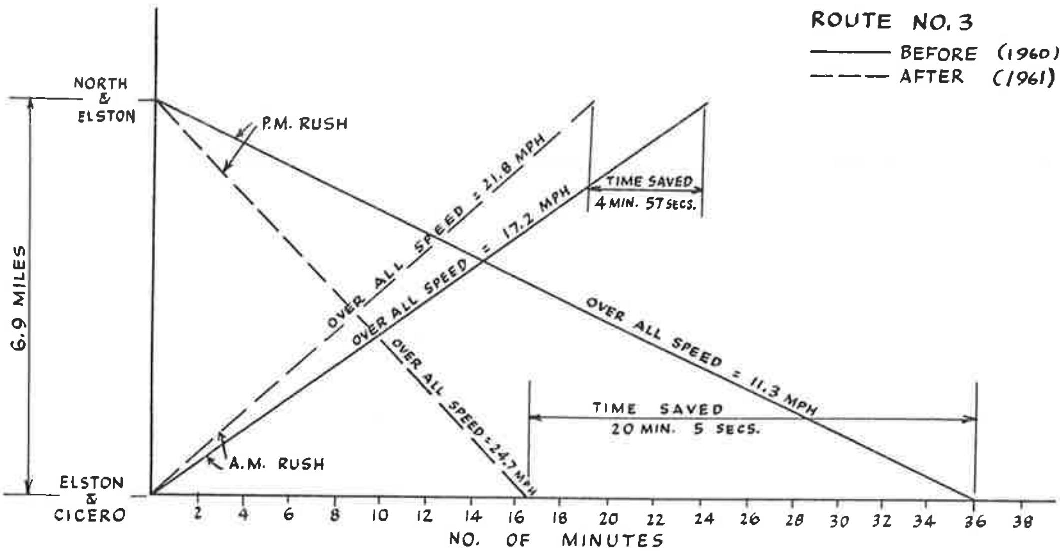


Figure 9. Travel times before and after opening of Northwest Expressway, Route 3.

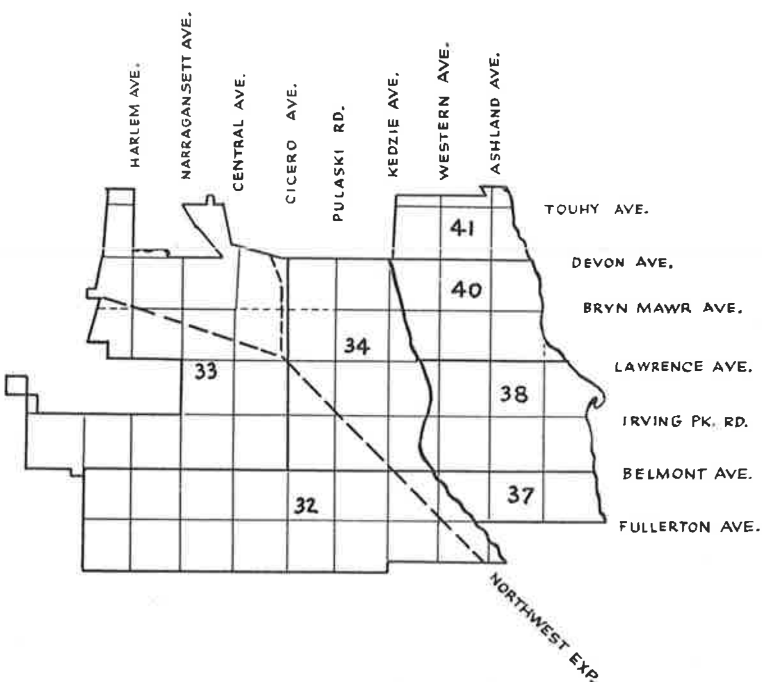


Figure 10. Northwest Expressway area police districts.

for that year on this system is (204 × 2,502.50)/100,000,000 = $0.0051 per vehicle-mile.

In 1961, the number of accidents per 100 mvm on this system was 225. The cost is (225 × 2,502.50)/100,000,000 = $0.0056 per vehicle-mile.

The computation for Lake Shore Drive for 1960 is (35 × 2,502.50)/100,000,000 = $0.0088 per vehicle-mile and $0.0088 × 166,000,000 × 2 = $292,000. For 1961,

TABLE 11

FATAL AND INJURY ACCIDENT SUMMARY ON 3 MAJOR ROUTES
(FIRST 6 MONTHS 1960 VS SAME PERIOD 1961)

Route No.	Street	Section	No. of Accidents 1960 Other	1960 Ped.	1960 Total	1961 Other	1961 Ped.	1961 Total	Accidents per 100 MVM 1960	Accidents per 100 MVM 1961
1	Lincoln Ave.	Devon-Peterson	9	0	9	15	3	18		
	Peterson Ave.	Lincoln-Ridge	35	4	39	31	1	32		
	Ridge Ave.	Peterson-Hollywood	19	2	21	16	1	17		
	Subtotal		63	6	69	62	5	67	252	306
2	Foster Ave.	Cicero-Sheridan	63	13	76	35	9	44	332	273
3	Elston Ave.	Cicero-North	22	7	29	15	3	18	82.3	93.8
Total for arterial streets			148	26	174	112	17	129	204	225
Lake Shore Drive		Hollywood-Ohio	54	4	58	44	4	48	35	32.4

(32.4 × 2,502.50)/100,000,000 = \$0.0081 per vehicle-mile and \$0.0081 × 140,000,000 × 2 = \$227,000. Annual saving on Lake Shore Drive = \$292,000 - \$227,000 = \$65,000.

All Affected Streets.—The computation of total savings due to accident reduction netted on all streets influenced by the new highway is accomplished by applying the mileage in Table 12 to all vehicle mileage on arterial streets. This total travel, together with the streets included, is given in Tables 13 and 14.

From this information, the computation for monetary saving on the entire arterial system due to lower traffic volumes is as follows:

For 1960, 434,000,000 × \$0.0051 =	\$2,212,500
For 1961, 337,661,500 × \$0.0056 =	1,896,000
Saving	\$ 316,500

The total saving due to lower accident rate for all influenced arterial streets and Lake Shore Drive is:

Arterial streets =	\$316,500
Lake Shore Drive =	65,000
	\$381,500

However, it is necessary to subtract from \$381,500 the cost of accidents on Northwest Expressway by those vehicles that previously used the arterial streets and Lake Shore Drive. The cost of their accident experience on the Northwest is computed as follows:

Total distance, Edens to Ohio Street	= 6.5 mi
Average daily volume (1961)	= 122,000
Number of injury accidents (1961)	= 146
Number of accidents per 100 mvm	= 49.5
Number of annual vehicle-miles transferred to Northwest Expressway:	
Arterial	= 97,000,000
Lake Shore Drive	= 52,000,000
Cost of accidents by transferred traffic	= \$184,000

Therefore, the total annual monetary saving due to accident reduction on parallel routes is \$381,500 - \$184,000 = \$197,500. This computation is summarized in Table 15.

TOTAL BENEFITS TO USERS OF ARTERIAL STREETS

Fuel Saving

The total annual vehicle-miles traveled on the arterial streets is 337,661,500 (Table 13). The saving in fuel was calculated earlier as follows:

TABLE 12

VEHICLE-MILES TRAVELED ON THREE PRINCIPAL ROUTES 6 MONTHS BEFORE AND AFTER OPENING OF NORTHWEST EXPRESSWAY

Route No.	Semi-Annual Vehicle-Miles Traveled	
	1960	1961
1	27,400,000	21,950,000
2	22,850,000	16,242,000
3	35,200,000	19,162,500
Total for arterial streets	85,450,000	57,354,500
Lake Shore Drive	166,000,000	140,000,000

TABLE 13

ANNUAL VEHICLE MILEAGE[a] ON ALTERNATE ARTERIAL ROUTES BEFORE OPENING OF NORTHWEST EXPRESSWAY

Street	No. of Miles	24-Hr Volume	Total Daily Vehicle-Miles
Peterson Ave.	3.8	35,300	134,000
Ridge Road	1.0	44,000	44,000
Foster Ave.	5.1	24,500	125,000
Lawrence Ave.	5.0	21,900	109,500
Montrose Ave.	5.0	16,850	84,500
Irving Pk. Rd.	4.2	27,600	116,000
Addison St.	3.6	12,900	46,500
Belmont Ave.	3.4	12,400	42,100
Diversey Ave.	3.0	17,650	53,000
Fullerton Ave.	2.4	19,300	46,500
Elston Ave.	6.9	27,800	192,000
Lincoln Ave.	5.2	15,400	80,000
Milwaukee Ave.	5.5	20,000	110,000
Total			1,183,100

[a]1,183,100 × 365 = 434,000,000 vehicle-miles per year (1960). 925,100 × 365 = 337,661,500 vehicle-miles per year (1961).

Arterial streets = 0.013 gal per vehicle-mile
Lake Shore Drive = 0.011 gal per vehicle-mile

By applying this fuel factor to the vehicle mileage during the rush hour over the entire system, the fuel saving benefit can be derived in actual monetary value.

In deriving the vehicle-miles traveled over the entire system, it becomes necessary to derive the rush hour directional traffic flow for each of the major streets influenced by the Northwest Expressway. This was accomplished by applying known traffic characteristics in Chicago (14). The Chicago rush-hour peak has been found to be 11 percent of the 24-hr daily volume. The predominant flow during the rush hour is 60 percent of the peak-hour total. Consequently, the formula used in deriving peak-hour directional flow is

$$C = 0.11V \times 0.60 = 0.066V$$

in which

C = peak-hour flow, and
V = 24-hr daily volume.

The entire peak-hour total consisted of four hours, 7 to 9 AM and 4 to 6 PM. Thus, the formula used was

$$C = 4 \times 0.066V$$

These calculated directional flows are given in Table 16. Knowing the street mileage and peak-hour volumes, the amount of gasoline saved is derived by the following computation:

1. Arterial Streets.—The total rush hour mileage is 244,150 (Table 16). The amount of gas saved on this system since the opening of the expressway is 0.013 gal per mi. Assuming a price of $0.33 per gal, including gas tax, the total monetary saving on this system is 244,150 × 0.013 × 0.33 × 261 = $274,000.

2. Lake Shore Drive.—The amount of money saved by less fuel used on this expressway is 214,000 × 0.011 × 0.33 × 261 = $204,000.

Accident Reduction

The amount of money motorists saved from accident reduction over the entire area influenced by the expressway was analyzed earlier. Summarizing the results of that study, the annual monetary saving is $234,000.

Time Saved

The daily time saved during the rush hour on the entire street system is recorded (Table 14). This is based on an average saving of 0.85 min per vehicle-mile on the arterial system and 0.50 min on the Lake Shore Drive. Using this factor, the total annual time saved is as follows: on arterial streets (207,600 × 251 days)/60 = 871,920 hr; on Lake Shore Drive (182,000 × 251 days)/60 = 762,000 hr for a total of 1,633,920 hr. The amount of money annually saved = 1,633,920 × $1.17 = $1,910,000.

Northwest Expressway Benefit

A recent study of the economic value of Northwest Expressway revealed that the annual monetary saving of that highway resulting from lower fuel costs, maintenance cost, and accident rates, amounts to $12,400,000 annually (13). The added benefits of this expressway in terms of monetary savings accrued on previous routes used by present expressway traffic.

TABLE 14

ANNUAL VEHICLE MILEAGE ON ALTERNATE ARTERIAL ROUTES AFTER OPENING OF NORTHWEST EXPRESSWAY

Street	No. of Miles	24-Hr Volume	Total Daily Vehicle-Miles
Peterson Ave.	3.8	29,000	110,000
Ridge Road	1.0	33,000	33,000
Foster Ave.	5.1	17,800	89,000
Lawrence Ave.	5.0	19,300	96,500
Montrose Ave.	5.0	14,000	70,000
Irving Pk. Rd.	4.2	21,300	89,500
Addison St.	3.6	11,500	41,500
Belmont Ave.	3.4	11,050	37,500
Diversey Ave.	3.0	17,050	51,100
Fullerton Ave.	2.4	20,400	49,000
Elston Ave.	6.9	15,000	103,500
Lincoln Ave.	5.2	11,750	61,000
Milwaukee Ave.	5.5	17,000	93,500
Total			925,100

Total Monetary Saving

The annual monetary saving to motorists now traveling major arterial streets in the area of the Northwest Expressway is as follows:

Fuel saving on arterial system	$ 274,000
Fuel saving on Lake Shore Drive	204,000
Accident reduction cost	197,500
Time saving	1,910,000
Total annual saving	$2,585,500

TABLE 15

SUMMARY OF COST OF ACCIDENTS ON ALTERNATE ARTERIAL STREETS AFFECTED BY OPENING OF NORTHWEST EXPRESSWAY

Category	Annual Volume in 100 MVM		Injury Accident Rate per 100 MVM		No. of Accidents		Change in Accidents	
	Before	After	Before	After	Before	After	Number	Value ($)
Alternate arterial streets	4.34	3.37	204	225	885	758	-127	-318,000
Traffic diverted from arterials to Expressway	0	0.97	-	49.5	-	48	+ 48	+120,000
Traffic diverted from Lake Shore Drive to Expressway	0	0.52	-	49.5	-	25.8	+ 25.8	+ 64,000
Lake Shore Drive	3.32	2.80	35	32.4	116.2	90.8	- 25.4	- 63,500
Total	7.66	7.66	-	-	1,001.2	922.6	- 78.6	-197,500

TABLE 16

TOTAL PEAK-HOUR DIRECTIONAL TRAFFIC VOLUME[a] AND GAS-TIME SAVED ON PARALLEL ROUTES AFTER OPENING OF NORTHWEST EXPRESSWAY

Street	No. of Miles	Avg. 4-Hr. Peak Total	Total Daily Vehicle-Miles	Daily Gas Saved (gal)	Daily Time Saved (min)
Peterson Ave.	3.8	7,650	29,100	378	24,800
Ridge Rd.	1.0	8,720	8,720	116.0	7,400
Foster Ave.	5.1	4,700	23,900	310.5	20,300
Lawrence Ave.	5.0	5,110	25,600	332.0	21,700
Montrose Ave.	5.0	3,710	18,550	240.5	15,750
Irving Pk. Rd.	4.2	5,620	23,600	307.0	20,000
Addison St.	3.6	3,030	10,900	143.0	9,250
Belmont Ave.	3.4	2,920	9,930	129.0	8,450
Diversey Ave.	3.0	4,550	13,650	177.0	11,600
Fullerton Ave.	2.4	5,380	12,800	166.5	10,900
Elston Ave.	6.9	3,960	27,300	354.0	23,200
Lincoln Ave.	5.2	3,100	15,700	204.0	13,350
Milwaukee Ave.	5.5	4,490	24,600	320.0	20,900
Total arterial streets	54.10	62,940	244,150	3,177.5	207,600
Lake Shore Drive	6.0	35,600	214,200	2,780.0	182,000

[a]Peak-hour total traffic volume includes traffic between hours of 7 to 9 AM and 4 to 6 PM.

SUMMARY OF STUDY

The opening of the Northwest Expressway has definitely changed traffic characteristics on major routes influenced by the freeway. Time studies, fuel consumption tests, and accident analyses made before and after the opening of the new highway reveal the following information:

1. Average saving in gas per mile on arterial system is 0.013 gal.
2. Average saving in gas per mile on Lake Shore Drive is 0.011 gal.
3. Traffic volume on the major streets was reduced by 31.5 percent, and Lake Shore Drive experienced a decrease of 17.0 percent.
4. The average saving in time per mile on major arterial streets is 0.85 min.
5. The average saving in time per mile on Lake Shore Drive is 0.5 min.
6. Fatal and injury accidents were reduced 25.8 percent on major arterial streets and 17.0 percent on Lake Shore Drive.
7. Accident reduction influenced by diversion of traffic to the new expressway amounts to a total monetary value of $197,500 per year.
8. The annual saving of fuel cost totals $478,000 for vehicles using the alternate routes.
9. The annual driving time saved by motorists using the alternate routes is 1,633,920 hr.
10. The annual monetary saving in time is $1,910,000.
11. The total economic value of the Northwest Expressway to those highway users, using major arterial streets in the vicinity of the expressway, amounts to $2,585,500 annually.

COMMENTS REGARDING STUDY

The tangible benefits derived from expressway driving is without question. This economic improvement has often been expressed in terms of time saved, accident reduction, ease of driving, and operating costs. The effect that Northwest Expressway has had in reducing travel times in the Metropolitan Area of Chicago has been reported elsewhere (13). That report demonstrates how this expressway will save motorists $12,400,000 a year.

In analyzing the effect of the Northwest Expressway on other major routes in its area, the report has demonstrated that the benefits derived are very significant and deserve the attention of highway planners seeking the entire answer to cost benefits of expressways. This is a bonus that is overlooked.

There is one factor not considered in this study—the additional traffic burden placed on intersections located close to ramps of the expressway. No attempt was made to place a value on this increased cost of congestion. This should be included in a comprehensive study.

Another weakness in this study is the omission of some additional routes influenced by the expressway. In future studies, more detailed traffic volume counts should be obtained so that a greater number of affected routes are included. By doing this, the additional benefit of the expressway to the major arterial users will be even greater than the data presented in this study.

The expressway, as this study revealed, has benefited motorists using arterial streets. These benefits have been measured in terms of money saved from lower fuel costs, less accidents, and faster travel time. The increased mobility of these arteries also has been advantageous to transit operation as well as transportation of cargo by commercial fleet operators.

In summary, future highway benefit studies should include the bonus values received by a reduction of travel on arterial streets affected by an expressway. This monetary value can be readily predicted, and the value derived demonstrates an additional benefit resulting from the construction of a modern expressway.

REFERENCES

1. "The Sagamore Conference on Highways and Urban Development." Syracuse University (1958).
2. Bacon, E. N., "Highways and Capital Programing." HRB Proc., 40:45-50 (1961).
3. Claffey, P. J., "Time and Fuel Consumption for Highway User Benefit Studies." HRB Bull. 276, 20-34 (1960).
4. "Chicago Public Works Annual Report." City of Chicago (1960).
5. Coleman, R. B., "A Study of Urban Travel Times in Pennsylvania Cities." Pennsylvania Department of Highways (1959).
6. Schwender, H. C., Normann, O. K., and Granum, J. O., "New Methods of Capacity Determination for Rural Roads in Mountainous Terrain." HRB Bull. 167, 10-37 (1957).
7. Gardner, E. H., "The Congestion Approach to Rational Programming." HRB Bull. 249, 1-22 (1960).
8. Sawhill, R. B., and Firey, J. C., "Motor Transport Fuel Consumption Rates and Travel Times." HRB Bull. 276, 35-91 (1960).
9. Frye, F., "The Effect of an Expressway on an Area—Accidents." CATS Research News, p. 9 (Dec. 1, 1961).
10. Johnston, E. J., "Economic Cost of Traffic Accidents in Relation to Highway Planning." HRB Bull. 263, 50-53 (1960).
11. Hewes, L. I., and Oglesby, C., H., "Highway Engineering." Wiley.
12. Sielski, M. C., "Economic Value of Chicago's Expressways." Chicago Motor Club (1957).
13. Sielski, M. C., "What the Northwest Expressway Will Mean to Chicagoland Motorists." Chicago Motor Club (1960).
14. Haikalis, G., and Joseph, H., "Economic Evaluation of Traffic Networks." Chicago Area Transportation Study (1961).

15. Smith, Wilbur and Associates, "Future Highways and Urban Growth." (1961).
16. Hoch, I., "Accident Experience—Expressways vs. Arterials." Chicago Area Transportation Study (1959).
17. Haikalis, G., and Joseph, H., "Economic Evaluation of Traffic Network." HRB Bull. 306, 39-63 (1961).