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Shoulder Use on an Urban Freeway

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This project consists of the establishment of a comprehensive system of surveillance and control on an urban freeway. The purposes of the project are to evaluate the use of surveillance, traffic control and sensing equipment; to investigate the characteristics of the freeway traffic flow which may be determined and treated by such equipment; to improve freeway traffic operation and safety by these means, as well as to conduct basic research into freeway operations by making use of this specialized equipment. For the first time it is possible to assemble the specialized equipment required to carry on a project of this scope.

This report pertains to one of a number of individual studies to be performed. Each of the studies will be reported separately as it is completed and each will contribute to the overall objective of this study.

• THE USE of shoulders on the highway has become a subject of increasing interest to authorities. In highway planning, design and operations, shoulder usage has grown from relative unimportance to a factor of major consideration along with volume, cross-section, speed and other related conditions. The major development which brought this about was probably control of access. By elimination of almost all elements of marginal friction, the principal remaining one, shoulder usage, can have a considerable effect on traffic flow on the controlled access facility. On such a facility, a driver has no refuge other than the shoulder.

The need for adequate shoulders is now commonly accepted. Design features have improved through the years and modern standards call for shoulder continuation even across some bridges. The effect of shoulder usage on moving traffic has been studied and the results published by the Highway Research Board and elsewhere.

A final question concerns the extent and nature of the shoulder usages that actually occur. The answer can be of value to those who design efficient freeways, control such usage or aid the shoulder user, and to those concerned with the improvement of traffic operations.

OBJECTIVES

The general objective is to determine the extent of shoulder usage on an urban freeway and the typical characteristics of this usage. In particular, the objectives are to study:

1. The 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 the same incident.
7. The findings in relation to other shoulder usage studies.

Paper sponsored by Committee on Operational Effects of Geometrics.

PREVIOUS STUDIES

There is other information on shoulder usage available from previous studies (1-4). These reports were studied both for comparative results and for methods of conducting such a study.

In general, it seems that the previous studies are not directly comparable to this study. Some studies were primarily on rural highways with varying cross-section and design standards. Although others obtained more detailed information on the driver and his reason for stopping, full-time coverage was not possible because of the methods used. In one case, there was full-time coverage on a short "control" section; otherwise, data were generally obtained by observers driving back and forth over the study section.

It is likely that shoulder usage in urban areas is quite different because of the great difference in trip length and purpose, driving time, access to assistance and time between stops. However, some of the previous findings are noted in the analysis which follows.

STUDY SITE AND FACILITIES

The study location was the John C. Lodge Freeway between the Edsel Ford and Davison Interchanges, a distance of 3.2 miles, in midtown Detroit. The Lodge Freeway is a depressed facility with full control of access. The study section was built between 1950 and 1955. There are no major interchanges between the two boundaries indicated, but there are five on-ramps and five off-ramps for northbound traffic, and six on-ramps and five off-ramps for southbound traffic including the two boundary interchanges. Roadways are four lanes in each direction for about half the length of the section, and three lanes in each direction for the remainder. The continuous shoulders are 8 ft wide, bituminous paved, and have a mountable curb between them and the through lane. The 3.2 miles of freeway are covered by 14 closed-circuit television cameras spaced from 800 to 1,800 ft apart (Fig. 1).

The cameras are equipped with regular wide-angle and telescopic lenses which can be changed on any camera, remotely by the observer, to provide the desired detail of coverage. The cameras can also be rotated both horizontally and vertically by the operator. All data were collected from the control center which is located in a building adjacent to the freeway at about the mid-point of the study section.

Although the total length of the project section is 3.2 miles, there are blind spots. The horizontal sweep of the camera is only 60 degrees, so the shoulders immediately adjacent to the structures on which the cameras are located are not visible. In a few cases the distance between cameras is greater than the usable camera range and thus blind spots exist at the extremities of the camera field. These blind spots will be located and measured as a part of a study on equipment limitations. Because the information is not yet available, determination of only 2.5 miles of visible roadway was used in the computation of vehicle-miles. Because the camera fields show both directions of traffic, the 2.5 miles of visible roadway actually include 5 miles of shoulder.

Traffic volume information was obtained by ultrasonic detecting equipment located over each lane of the freeway at two locations.

The project facilities are especially useful in this type of study because continuous observation over an extensive length of urban freeway is possible under all conditions, and inasmuch as drivers are unaware that they are being observed and studied, their normal behavior is not affected.

METHOD OF STUDY

The data were obtained by trained observers watching the monitors. When a shoulder usage was observed the time and location were recorded on the log, and remaining data were recorded as they were determined. Location was indicated by using camera number and direction of travel, that is, 1^i—Camera No. 1, inbound (Fig. 2).

In this study, no attempt was made to determine the number of incidents that were missed by the observers. It is assumed that their accuracy was good, subject to the completion of an observer evaluation study which will be reported separately. It is known, however, that some incidents were missed so the results derived from the data should be on the conservative side.

The "reason for stoppage" was determined entirely by the trained observer's evaluation of the incident from his location at the television control center. If there was no obvious indication, the reason for stopping was indicated as "undetermined." No attempt was made to determine the reason for stopping by sending someone to the scene or by notifying the police, because a part of this study was to determine the length of stay under normal conditions. This, of course, was not the case in any situation involving injury accidents or severe emergency conditions.

The traffic volume data were collected from automatic vehicle detectors and recorded at specified times from the visual dials of this equipment to determine vehicle-mile information. This volume is assumed to represent the average volume over the entire study section because the only major interchanges are located at the extreme ends of the study section. Ramp volumes throughout the section will be observed and reported in another study.

DATA COLLECTION

The field studies were conducted in May and August of 1961. In May, the study was performed during the period Monday the 15th to Friday the 26th, which included one weekend. The hours of study each day were 6 AM to 8 PM. Observer's shifts were changed during the middle of the day without interruption to the data collection.

The August studies included only weekdays. Observations were made from 6 AM to 1 PM and 1 PM to 8 PM on alternate days.

Data for 168 hours of observation were recorded during the twelve days in May and 70 hours during ten days in August for a total of 238 man-hours of observer time.

All data for twelve days in May were complete so that it was possible to include all in the summaries and tables. Portions of the August data were unusable because reliable volume information was not available. Therefore, data for August cover only seven days of seven hours each.

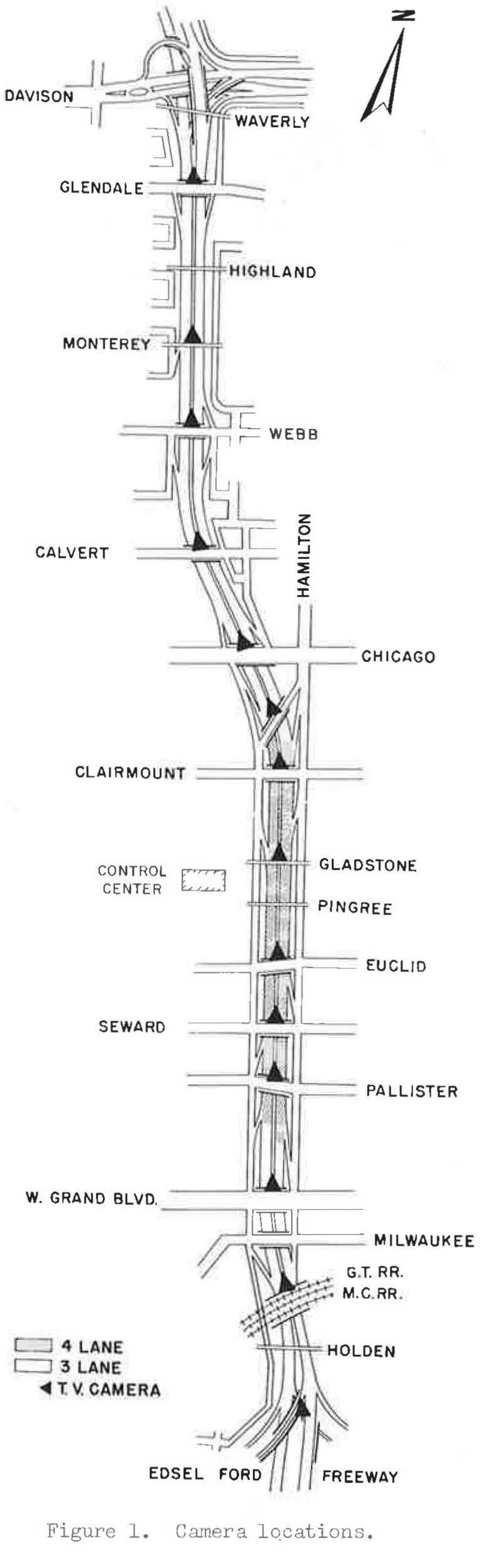

Figure 1. Camera locations.

VOLUME

	CHICAGO (OUTBOUND)	CHICAGO (INBOUND)
0600 1000	10533	11766

STUDY 417 "SHOULDER USAGE" DATE 5-23-61 DAY TUES OBSERVER J.L.&C.R. TIME STARTED 0600

TIME IN	LOCATION	TYPE of VEHICLE	CAUSE	AID REC'D	AIDED BY	TIME OUT	RD. SURFACE	WEATHER
071000	1'	FOREIGN	OUT OF GAS		SELF	074030	DRY	CLEAR
072100	9'	STAND PASS	MOTOR TR.		SELF	072400	"	"
072200	8°	" "	REC'D TICKET			072400	"	"
072200	8°	MOTORCYCLE	ISSUE TICKET			072400	"	"
083300	8°	STAND PASS	REC'D TICKET			083415	"	"
083300	8°	MOTORCYCLE	ISSUE TICKET			083415	"	"
084300	3'	STAND PASS	OVERHEATED	GOT WATER FOR RADIATOR	WKMH	084730	"	"
084330	3'	STAND (WKMH)	TO OFFER ASSIST.			084730	"	"
091000	11°	COMBINATION	CHECK MOTOR			091100	"	"
091515	9'	COMBINATION	ADJ CARGO			092200	"	"
092545	12'	COMPACT	UNDETER			092900	"	"
102630	12'	STAND PASS	FLAT TIRE		SELF	103705	"	"
103240	9'	SINGLE UNIT	FLAT TIRE	TIRE CHANGE	2 PASS MOTOR	111230	"	"
105155	9'	STAND PASS	TO OFFER ASSIST			110735	"	"
105245	9'	PANEL	"			111215	"	"
110205	3'	SINGLE UNIT	UNDETER.			110240	"	"
111005	5'	SINGLE UNIT	"			111210	"	"
111009	5'	SINGLE UNIT	"			111213	"	"
111805	10'	STAND POLICE	CALL IN			111840	"	"
113200	9°	" "	"			113355	"	"
115525	11°	STAND PASS	UNDETER.			115625	"	"
121919	13'	COMBINATION	REC'D TICKET			122610	"	"
121930	13°	STAND (POLICE)	ISSUE TICKET			122600	"	"
123140	10°	STAND PASS	MOTOR TRBL.		SELF	124545	"	"

NOTE: LOCATION INDICATED BY CAMERA NUMBER AND DIRECTION OF TRAVEL, ie 10'-CAMERA 10 FIELD OF VIEW INBOUND, 11°-CAMERA 11 FIELD OF VIEW OUTBOUND.

Figure 2. Log sheet.

In order to determine how traffic volumes during May and August were related to volumes throughout the year, comparisons were made with data from a permanent traffic count station ¼ mile south of the study section. At that location, May and August volumes were 102.6 and 100.3 percent, respectively, of the average monthly traffic.

ANALYSIS AND RESULTS

The data collected were divided into three basic groups: May weekdays, May weekend, and August weekdays. Data were analyzed and summarized separately for each of the groups.

Table 1 gives a general summary of the three study periods. It is interesting to note that the average use per hour during the weekday periods in May and August are so close together in spite of the differences in uses per 10,000 vehicle-miles. Note the difference in hours of observation between May and August weekdays which explains the difference in vehicle-miles and number of uses.

As previously mentioned, comparisons are not made with other usage studies but some previous results are shown. Billion (3) found one use per 2,100 vehicle-miles on New York rural highways having 2, 3 or 4 lanes in which the shortest average trip length was 150 miles. He also reported one use per 5,600 vehicle-miles on rural 4-lane facilities with volumes over 10,000 vehicles per day. Blensly and Byars (4) reported several rural rates ranging from one use per 318 vehicle-miles to one use per 1,900 vehicle-miles.

TABLE 1

COMPARISON OF PERIODS STUDIED

Period	Hours Observed	No. of Uses	Vehicle-Miles	Uses per 10,000 VM	VM per Use	Uses per Hr	Uses per Mi per Hr
May weekdays	140	670	2,492,000	2.70	3,660	4.7	0.9
Aug. weekdays	49	221	929,400	2.38	4,220	4.5	0.9
May weekend	28	105	330,600	3.18	3,110	3.7	0.7
Total	217	996	3,752,000	2.68	3,770	4.5	0.9

TABLE 2

SHOULDER USAGE BY TYPE OF VEHICLE

Type	% of Type[1] in Traffic Stream	May Weekdays		August Weekdays		May Weekend	
		No.	%	No.	%	No.	%
Passenger							
Standard	80.6	418	62.4	152	68.8	85	81.0
Compact	6.8	8	1.2	2	0.9	0	0
Foreign	3.3	18	2.7	4	1.8	1	0.9
Commercial							
Panel/pick-up	3.8	45	6.7	9	4.1	4	3.8
Single unit	2.9	121	18.1	42	19.0	9	8.6
Combination	2.1	32	4.8	4	1.8	1	0.9
Other							
Motorcycle	0.1	27	4.0	8	3.6	5	4.8
Buses	0.4	1	0.1	0	-	0	0
Total	100.0	670	100.0	221	100.0	105	100.0

[1]Typical weekday.

In order to determine the percentage of each type of vehicle in the total traffic stream, classification data for a typical day was obtained from the volume and classification study for this project. The classifications used are standard BPR. This information is given in Table 2 which indicates the shoulder use by type of vehicle. The disparity between the composition of the traffic stream and the composition of vehicle types using the shoulder on weekdays indicates the importance of shoulders so far as trucks are concerned. It should be pointed out that inasmuch as the classification information relates to a typical weekday, no such comparison can be made for the weekend data. The comparison in the case of motorcycles is not valid because this type of shoulder usage is related to police activities and has no relationship to vehicle type.

Table 3 gives the reasons for the use of the shoulder. Even though, in all periods, "to offer assistance" was the most frequent single reason, this use would not have occurred if there had not been an earlier use for some other reason. The most frequent reasons for an initial usage were motor trouble and tire trouble. Some of the more infrequent causes for usages are given in Table 3.

Of course the infrequent uses could be grouped together, but the variety of reasons is interesting. For example, one driver stopped on the shoulder, walked up the em-

TABLE 3

REASON FOR USAGE

Reason	May Weekdays		August Weekdays		May Weekend	
	No.	%	No.	%	No.	%
Motor trouble	70	10.4	17	7.8	10	9.5
Tire trouble	62	9.3	17	7.8	12	11.4
To offer assistance	120	18.0	30	13.6	17	16.2
Received ticket	51	7.7	14	6.3	8	7.6
Out of gas	11	1.6	4	1.8	2	1.9
Check tires	8	1.2	4	1.8	1	0.9
Police—use call box	14	2.1	4	1.8	3	2.9
Police— issue ticket	40	6.0	14	6.3	8	7.6
Adjust cargo	21	3.1	4	1.8	1	0.9
Check motor	4	0.6	–	–	1	0.9
Retrieve hub cap	1	0.1	–	–	1	0.9
Fasten hood	–	–	1	0.4	1	0.9
Accident	51	7.7	5	2.3	–	–
Freeway maintenance	10	1.5	6	2.7	–	–
Conversation	2	0.3	4	1.8	–	–
Discharge passengers	2	0.3	3	1.4	–	–
Police—conversation	–	–	2	0.9	2	1.9
Transfer load	1	0.1	–	–	–	–
Clean windows	3	0.4	–	–	–	–
Retrieve cargo	1	0.1	–	–	–	–
Work on vehicle	6	0.9	–	–	–	–
Police—switch drivers	1	0.1	–	–	–	–
WKMH call-in	1	0.1	–	–	–	–
Use call box	–	–	1	0.4	–	–
Raise convertible top	–	–	1	0.4	–	–
Converse with police	–	–	2	0.9	–	–
Pick up object	–	–	1	0.4	–	–
Check front end	–	–	–	–	1	0.9
Undetermined	190	28.4	87	39.4	37	35.2
Total	670	100.0	221	100.0	105	100.0

bankment and across the service road to a house. A little later, he came out of the house, returned to his car and drove off.

Uses involving accidents do not seem proportionally great nor do uses for roadway maintenance purposes. It should be noted that a maintenance vehicle might travel the shoulder for some distance and stop occasionally. In this case, no usage was recorded unless the vehicle moved back and forth into the traffic stream.

Table 4 indicates the range of duration, total time, and average and median duration of stay of shoulder usages. The ranges are quite widespread for all three study periods, but only a few vehicles stayed for the longer periods of time. This is further indicated by the comparison of the average and median lengths of stay. Although the average length of stay is much higher and quite different from weekday to weekend, the median lengths of stay for all three periods are approximately the same and all are under 5 minutes.

Table 5 is related to the "to offer assistance" reason (see Table 3) in that is shows the source of aid.

On Detroit freeways, Wayne County Road Commission wreckers patrol the facilities and are only authorized to move vehicles to the shoulder or to perform simple mainten-

TABLE 4

LENGTH OF USAGE

Time	May Weekdays	August Weekdays	May Weekend
Range	9 sec to 5 hr, 45 min, 0 sec	10 sec to 4 hr, 43 min, 40 sec	18 sec to 19 hr, 6 min, 30 sec
Total	176 hr, 38 min, 46 sec	31 hr, 27 min, 34 sec	49 hr, 41 min, 39 sec
Average	15.8 min	8.54 min	28.4 min
Median	4.5 min	2.75 min	3.75 min

TABLE 5

SOURCE OF AID

Source	May Weekdays	August Weekdays	May Weekend
	No. of Aids	No. of Aids	No. of Aids
Passing motorist	53	14	7
Police	13	2	4
Wrecker	47	4	6
WKMH[1]	7	10	-
Total	120	30	17

[1] Radio station vehicle.

ance. All other wrecker service must be called. This prohibits commercial wrecking services from patrolling freeways looking for business. The police stop and aid shoulder users to the extent of providing a list of available wreckers and calling the one chosen by the motorist. They also provide sufficient gas to enable the motorist to reach a gas station. WKMH vehicles will, on occasion, aid in the same manner. WKMH is a local radio station which operates a freeway patrol that broadcasts traffic information from 6:30 AM to 9:30 AM, and 3:30 PM to 6:30 PM.

The interesting and unexpected data in the table is the amount of assistance provided by passing motorists. As explained earlier, no attempt was made to go to the scene and determine what this assistance consisted of.

Table 6 indicates the length of time a shoulder user had to wait for outside aid. This table shows no apparent relation between the length of wait and the source of aid received. It points again to the consideration shown by fellow motorists.

The total column indicates that on weekdays, assistance was offered in less than 15 min in 60 percent of the cases. On the weekend, the reverse is true. More than half the vehicles had to wait more than 60 min for assistance.

Table 7 relates the reason for the use of the shoulder with the duration of stay. As might be expected, motor and tire trouble are the major causes of vehicles staying on the shoulder for longer periods of time. Nearly all of the undetermined usages fell in the duration category of less than 15 minutes. For no reason visible to the observer, a great number of vehicles simply pull onto the shoulder for a few minutes and then leave. Perhaps this is to rest, to get one's bearings, or to read a map. In any case, they are a major contributer to shoulder usage.

TABLE 6

LENGTH OF WAIT FOR AID

Length of Wait	Source of Aid				
	Passing Motorists	Police	Wrecker	WKMH	Total
(a) May Weekdays					
Less than 1 min	8	3	3	0	14
1 min to 5 min	13	3	6	5	27
5 min to 15 min	12	4	13	1	30
15 min to 1 hr	10	3	18	1	32
Over 1 hr	10	0	7	0	17
Total	53	13	47	7	120
(b) August Weekdays					
Less than 1 min	4	2	–	4	10
1 min to 5 min	–	–	–	1	1
5 min to 15 min	3	–	1	3	7
15 min to 1 hr	5	–	3	2	10
Over 1 hr	2	–	–	–	2
Total	14	2	4	10	30
(c) May Weekend					
Less than 1 min	1	1	–	–	2
1 min to 5 min	1	2	1	–	4
5 min to 15 min	1	1	–	–	2
15 min to 1 hr	–	–	–	–	–
Over 1 hr	4	–	5	–	9
Total	7	4	6	–	17

Finally it should be noted that each incident involving use of the shoulder may involve one or several vehicles. In all previous tables, the actual number of vehicle usages regardless of their relation to other vehicle usages has been used.

Table 8 provides some gross information obtained by summarizing data to indicate as a single event all vehicles occupying the shoulder as a result of a single incident. For the purposes of this table, the number of vehicles using the shoulder was disregarded as long as all were related to a single incident. The rate of incidents is smaller than the rate of usages, but it does indicate the frequency of events that involve some amount of shoulder usage.

FINDINGS

Based on the analysis of data obtained on the John C. Lodge Freeway in Detroit for 19 days, the following findings are indicated:

1. There was an incident involving one or more vehicles using the shoulder for every 5,300 vehicle-miles of travel during the overall study period.

2. There were 996 vehicles or individual shoulder uses involved in the 711 incidents observed, representing an average of one usage per 3,800 vehicle-miles, or more than 4.5 uses per hour over a study section of 2.5 miles.

TABLE 7

CAUSE AND LENGTH OF SHOULDER USAGE

Reason	Duration of Stay																	
	Less than 15 Min	15 to 30 Min	30 to 45 Min	45 Min to 1 Hr	1 Hr to 1 Hr 15 Min	1 Hr 15 Min to 1 Hr 30 Min	1 Hr 30 Min to 1 Hr 45 Min	1 Hr 45 Min to 2 Hr	2 Hr to 2 Hr 15 Min	2 Hr 15 Min to 2 Hr 30 Min	2 Hr 30 Min to 2 Hr 45 Min	2 Hr 45 Min to 3 Hr	3 Hr to 3 Hr 15 Min	3 Hr 15 Min to 3 Hr 30 Min	3 Hr 30 Min to 3 Hr 45 Min	3 Hr 45 Min to 4 Hr	Over 4 Hr	Total
(a) May Weekdays																		
Motor trouble	34	8	5	4	5	3	1	1	-	-	1	2	-	-	1	1	1	67
Tire trouble	24	14	10	4	4	1	1	-	-	-	-	-	-	1	-	-	2	61
To give aid	105	11	2	1	1	-	-	-	-	-	-	-	-	-	-	-	-	120
Received ticket	48	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	50
Out of gas	4	4	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	10
Check motor	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
Check tires	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
Police—call-in	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14
Police—issue ticket	39	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	39
Retrieve hub cap	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Accident	18	16	9	2	-	1	-	1	-	1	-	-	-	-	-	-	-	48
Adjust cargo	21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21
Freeway maintenance	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
Transfer load	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1
Conversation	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Police—switch drivers	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Clean windows	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Retrieve cargo	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
WKMH call-in	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Discharge passengers	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Miscellaneous work	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
Undetermined	173	4	1	2	1	-	-	-	-	-	-	-	1	2	-	-	2	186
(b) August Weekdays																		
Motor trouble	8	4	2	1	-	-	-	-	-	1	-	-	-	-	-	-	-	16
Tire trouble	10	4	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	16
To give aid	28	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	30
Received ticket	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14
Out of gas	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
Check motor	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Check tires	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
Police—call-in	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
Police—issue ticket	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14
Freeway maintenance	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
Discharge passengers	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Check cargo	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
Driver used call box	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Accident	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Drivers talking	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
Put up top	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Talk to police	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Picked something up	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Fasten hood	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Police conversation	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Undetermined	77	2	2	1	-	-	1	-	-	-	-	-	-	-	-	-	1	84
(c) May Weekend																		
Motor trouble	3	1	-	-	4	-	-	-	-	-	-	-	-	1	-	-	-	9
Tire trouble	5	3	-	-	1	-	1	-	1	-	-	-	-	-	-	-	-	11
To give aid	12	3	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	17
Received ticket	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
Out of gas	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Check motor	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Check tires	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Police—call-in	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Police—issue ticket	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
Fasten hood	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Retrieve hub cap	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Police—conversation	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Police—undetermined	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Check front end	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Adjust cargo	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Undetermined	30	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	34

3. The percentage of vehicles using the shoulder that were trucks was consistently higher than the percentage of trucks in the traffic stream as a whole. The reverse was generally true for passenger cars.

4. The most frequent single reason for stopping that could be determined was because of, or to assist, another shoulder user. Motor and tire trouble were the next most frequent visible reasons.

5. During the study periods, an equal number of vehicles remained on the shoulder more than, and less than 3 to 5 minutes—the median range. The average length of stay was much higher because of a few vehicles remaining for many hours

6. In 44 percent of the cases where a second vehicle stopped to aid a previously stopped vehicle, the second vehicle was an ordinary passing motorist rather than a police or service vehicle.

7. On weekdays, about 60 percent of the motorists who received assistance had to wait less than 15 minutes. On the weekend, more than half the motorists receiving aid had to wait more than one hour.

TABLE 8

SHOULDER USE INCIDENTS

Period	May Weekdays	Aug. Weekdays	May Weekend
Vehicle-miles	2,492,000	929,400	330,600
No. of incidents (veh)	470 (670)	166 (221)	75 (105)
Incidents/veh-mi	1/5301	1/5602	1/4400

8. Shoulder usages for reasons that were not evident to the television observer constituted the greatest number of cases. Nearly all stayed less than 15 minutes. The necessity for these numerous usages on an urban freeway without visible reason is most intriguing and may prove important in further study.

There is additional information that can be obtained in this area. It is planned to collect the same type of data during winter and early spring in order to determine any effect of weather on the frequency or duration of shoulder usage. When this work is completed, another report will be issued which, in combination with this report, should provide more complete data on shoulder usage under varying weather conditions.

ACKNOWLEDGMENTS

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Appendix

TYPE OF VEHICLE AND DURATION OF STAY

May Weekdays

Type	Hr	Min	Sec	Type	Hr	Min	Sec
Standard	9	28	30	Standard	0	50	00
Standard	5	45	00	Comb.	0	49	30
Standard	5	27	15	Standard	0	49	10
Standard	4	58	15	Standard	0	47	40
Standard	4	27	40	Standard	0	46	50
Standard	4	18	00	Foreign	0	46	30
Standard	3	59	18	Police Call In	0	46	10
Standard	3	32	15	Single Unit	0	45	02
Standard	3	31	50	Standard	0	44	40
Standard	3	23	30	Standard	0	44	10
Single Unit	3	18	30	Standard (PD)	0	42	55
Standard	3	03	00	Standard (PD)	0	42	30
Single Unit	2	49	35	Standard (PD)	0	42	20

May Weekdays (continued)

Type	Hr	Min	Sec	Type	Hr	Min	Sec
Panel	2	49	35	Standard (PD)	0	42	15
Standard	2	39	00	Pick-Up	0	41	55
Single Unit	2	18	35	Standard	0	41	30
Standard	1	55	00	Wrecker	0	39	50
Foreign	1	48	55	Standard	0	39	30
Standard	1	38	00	Standard	0	38	30
Standard	1	31	35	Standard	0	37	35
Standard	1	29	50	Standard	0	37	30
Standard	1	29	30	Standard	0	35	40
Standard	1	27	50	Standard	0	35	25
Standard	1	18	47	Standard	0	34	15
Standard	1	18	00	Standard	0	33	55
Standard	1	17	15	Standard	0	33	50
Standard	1	12	55	Standard	0	33	50
Single Unit	1	12	50	Standard	0	33	00
Standard	1	11	40	Standard	0	32	45
Standard	1	11	35	Standard	0	32	30
Comb.	1	11	15	Standard	0	32	05
Standard	1	06	50	Comb.	0	32	00
Pick-Up	1	06	35	Standard	0	30	35
Standard	1	05	15	Foreign	0	30	30
Standard	1	03	45	Standard	0	30	00
Single Unit	1	03	35	Standard	0	29	50
Panel	1	01	30	Standard	0	28	55
Standard	1	00	40	Standard	0	28	25
Standard	1	00	30	Standard	0	28	20
Foreign	0	59	15	Standard	0	27	50
Standard	0	58	00	Standard	0	27	50
Standard	0	56	20	Pick-Up	0	27	45
Standard	0	54	00	Standard	0	27	00
Comb.	0	54	00	Panel	0	26	40
Standard	0	51	00	Panel	0	26	30
Standard	0	26	23	Cycle (PD)	0	15	00
Standard	0	26	05	Sgle.Unit(Wrkr)	0	14	55
Standard	0	25	45	Standard	0	14	45
Standard	0	24	40	Standard	0	14	45
Standard	0	24	20	Compact	0	14	45
Standard (PD)	0	24	10	Standard	0	14	35
Standard	0	24	10	Sgl.Unit(Wrkr)	0	14	30
Standard	0	24	00	Standard	0	14	10
Standard	0	24	00	Standard	0	14	05
Standard (PD)	0	23	30	Sgl.Unit(Wrkr)	0	14	00
Foreign	0	23	20	Foreign	0	13	55
Standard	0	22	55	Standard	0	13	40
Single Unit	0	22	50	Standard	0	13	40
Single Unit	0	22	50	Wrecker	0	13	15
Standard	0	22	50	Standard	0	13	15
Sgl. Unit (Wrkr)	0	22	35	Standard	0	13	15
Sgl. Unit (Wrkr)	0	21	50	Standard	0	13	05
Standard	0	21	10	Single Unit	0	12	45
Pick-Up	0	21	05	Standard	0	12	41
Pick-Up	0	21	00	Compact	0	12	40
Standard	0	20	50	P.D.	0	12	40
Standard (PD)	0	20	30	Standard	0	12	35
Comb.	0	20	15	Standard	0	12	35
Standard	0	20	00	Single Unit	0	12	30
Standard	0	20	00	Sgl.Unit (Wrkr)	0	12	25
Panel	0	19	30	Standard	0	12	00
Sgl.Unit (Wrkr)	0	19	15	Standard	0	12	00
Standard	0	19	00	Panel	0	12	00
Standard	0	18	55	Single Unit	0	11	50
Standard	0	18	55	Standard	0	11	50

May Weekdays (continued)

Type	Hr	Min	Sec	Type	Hr	Min	Sec
Standard	0	18	05	Standard	0	11	45
Standard (PD)	0	18	00	Standard	0	11	45
Standard	0	17	55	Standard	0	11	40
Standard	0	17	25	Pick-Up	0	11	30
Sgl.Unit (Wrkr)	0	17	10	Standard	0	11	30
Standard	0	17	00	Standard	0	11	30
Standard	0	16	30	Standard	0	11	20
Cycle (PD)	0	16	20	Single Unit	0	11	15
Standard	0	16	14	Standard	0	11	15
Compact	0	16	02	Standard	0	11	15
Standard	0	15	55	Standard (PD)	0	11	00
Sgl.Unit (PD)	0	15	45	Standard (PD)	0	11	00
Sgl.Unit (Wrkr)	0	15	40	Single Unit	0	11	00
Standard	0	15	40	Passenger	0	10	55
Single Unit	0	15	35	Cycle (PD)	0	10	50
Standard	0	15	30	Standard	0	10	45
Standard	0	15	30	Standard	0	10	45
Standard	0	15	25	Standard	0	10	40
Sgl. Unit(Wrkr)	0	15	15	Standard	0	10	40
Single Unit	0	15	15	Standard	0	10	30
Standard	0	15	13	Standard	0	10	25
Standard	0	15	00	Standard	0	10	25
Standard	0	10	00	Standard (PD)	0	7	00
Cycle	0	10	00	Single Unit	0	7	00
Sgl.Unit(Wrkr)	0	9	55	Sgl.Unit(Wrkr)	0	7	00
Sgl.Unit(Wrkr)	0	9	55	Sgl.Unit(Wrkr)	0	7	00
Standard (PD)	0	9	45	Pick-Up	0	7	00
Foreign	0	9	40	Standard	0	7	00
Standard	0	9	40	Standard	0	7	00
Single Unit	0	9	37	Single Unit	0	6	55
Standard	0	9	30	Standard	0	6	55
Comb.	0	9	20	Sgl.Unit(Wrkr)	0	6	55
Standard	0	9	20	Comb.	0	6	51
Standard (PD)	0	9	15	Standard	0	6	50
Standard	0	9	05	Comb.	0	6	50
Pick-Up	0	9	00	Standard (PD)	0	6	50
Sgl.Unit(Wrkr)	0	9	00	Single Unit	0	6	50
Standard	0	8	50	Comb.	0	6	45
Standard	0	8	50	Standard	0	6	45
Standard	0	8	48	Single Unit	0	6	45
Sgl.Unit(Wrkr)	0	8	40	Standard	0	6	40
Standard	0	8	25	Single Unit	0	6	40
Standard	0	8	25	Standard	0	6	35
Comb.	0	8	18	Police	0	6	30
Pick-Up	0	8	15	Wrecker	0	6	30
Standard	0	8	10	Standard	0	6	30
Standard	0	8	10	Single Unit	0	6	30
Sgl. Unit	0	8	05	Single Unit	0	6	30
Cycle	0	8	00	Comb.	0	6	25
Standard (PD)	0	8	00	Standard	0	6	25
Standard	0	7	55	Standard (PD)	0	6	25
Standard (PD)	0	7	55	Wrecker	0	6	20
Standard (PD)	0	7	55	Standard	0	6	15
Foreign	0	7	45	Single Unit	0	6	15
Standard	0	7	45	Compact	0	6	12
Single Unit	0	7	40	Sgl.Unit(Wrkr)	0	6	10
Sgl.Unit(Wrkr)	0	7	35	Standard	0	6	10
Single Unit	0	7	30	Standard (PD)	0	6	10
Standard	0	7	30	Standard	0	6	00
Sgl.Unit(Wrkr)	0	7	29	Single Unit	0	6	00
Standard (PD)	0	7	25	Standard	0	5	50
Standard	0	7	25	Standard	0	5	50

May Weekdays (continued)

Type	Hr	Min	Sec	Type	Hr	Min	Sec
Single Unit	0	7	20	Cycle (PD)	0	5	50
Standard	0	7	20	Panel	0	5	50
Standard (PD)	0	7	20	Foreign	0	5	50
Compact	0	7	15	Standard	0	5	46
Single Unit	0	7	15	Single Unit	0	5	45
Standard	0	7	15	Comb.	0	5	45
Sgl.Unit(Wrkr)	0	7	10	Cycle (PD)	0	5	45
Comb.	0	7	05	Standard	0	5	40
Sgl.Unit(Wrkr)	0	7	05	Standard	0	5	40
Single Unit	0	7	05	Standard	0	5	40
Comb.	0	7	05	Cycle (PD)	0	5	40
Standard	0	5	40	Single Unit	0	4	15
Standard	0	5	36	Standard	0	4	15
Foreign	0	5	35	Standard	0	4	15
Single Unit	0	5	30	Single Unit	0	4	15
Standard	0	5	30	Standard	0	4	10
Foreign	0	5	25	Cycle (PD)	0	4	09
Single Unit	0	5	15	Cycle (PD)	0	4	02
Foreign	0	5	15	Panel	0	4	00
Standard	0	5	15	Pick-Up	0	4	00
Standard	0	5	10	Standard	0	4	00
Pick-Up	0	5	10	Standard	0	4	00
Single Unit	0	5	10	WKMH	0	4	00
Standard	0	5	05	Standard	0	4	00
Standard	0	5	05	Wrecker	0	4	00
Single Unit	0	5	05	Standard	0	4	00
Single Unit	0	5	05	Standard (PD)	0	4	00
Comb.	0	5	00	Standard	0	3	59
Foreign	0	5	00	Standard	0	3	53
Wrecker	0	5	00	Single Unit	0	3	50
Standard	0	5	00	Pick-Up	0	3	50
Panel	0	5	00	Foreign	0	3	45
Standard	0	5	00	Standard	0	3	45
Standard	0	4	58	Standard (PD)	0	3	45
Comb.	0	4	55	Standard	0	3	35
Wrecker	0	4	55	Wrecker	0	3	35
Standard	0	4	55	Standard	0	3	35
Standard (PD)	0	4	50	Standard (PD)	0	3	35
Cycle (PD)	0	4	50	Standard	0	3	35
Standard	0	4	50	Pick-Up	0	3	35
Single Unit	0	4	50	Standard	0	3	30
Standard	0	4	45	Single Unit	0	3	30
Standard	0	4	45	Standard	0	3	29
Comb.	0	4	45	Standard	0	3	27
Comb.	0	4	45	Standard	0	3	25
Single Unit	0	4	45	Standard (PD)	0	3	25
Standard (PD)	0	4	40	Wrecker	0	3	20
Pick-Up	0	4	40	Standard	0	3	20
Cycle (PD)	0	4	40	Wrecker	0	3	15
Standard (PD)	0	4	31	Comb.	0	3	15
Standard	0	4	30	Compact	0	3	15
Panel	0	4	30	Standard	0	3	15
Standard	0	4	30	Single Unit	0	3	15
Standard	0	4	30	Standard	0	3	15
Single Unit	0	4	30	Sgl.Unit(Wrkr)	0	3	10
Standard	0	4	25	Standard	0	3	10
Single Unit	0	4	25	Pick-Up	0	3	05
Standard (PD)	0	4	20	Wrecker	0	3	05
Single Unit	0	4	20	Foreign	0	3	05
Standard	0	4	20	Foreign	0	3	05
Standard (PD)	0	4	15	Single Unit	0	3	00
Cycle (PD)	0	3	00	Panel	0	2	00

May Weekdays (continued)

Type	Hr	Min	Sec
Cycle (PD)	0	3	00
Standard	0	3	00
Standard (PD)	0	3	00
Standard	0	3	00
Standard	0	3	00
Bus	0	3	00
Standard	0	3	00
Standard	0	3	00
Cycle (PD)	0	2	55
Comb.	0	2	55
Standard	0	2	50
Wrecker	0	2	50
Standard	0	2	50
Cycle (PD)	0	2	50
Cycle (PD)	0	2	50
Standard	0	2	50
Standard (PD)	0	2	50
Single Unit	0	2	45
Standard	0	2	45
Standard (PD)	0	2	45
Standard	0	2	45
WKMH	0	2	45
Standard (PD)	0	2	40
Single Unit	0	2	40
Single Unit	0	2	40
Standard (PD)	0	2	40
Standard	0	2	35
Single Unit	0	2	35
Cycle (PD)	0	2	30
Standard	0	2	30
Standard	0	2	25
Standard	0	2	25
Standard	0	2	20
Comb.	0	2	20
Comb.	0	2	20
Standard	0	2	20
Standard	0	2	20
Pick-Up	0	2	20
Standard	0	2	19
Standard	0	2	15
Single Unit	0	2	15
Standard	0	2	15
Standard	0	2	10
Standard	0	2	10
Standard	0	2	10
Wrecker	0	2	05
Standard	0	2	05
Wrecker	0	2	05
Wrecker	0	2	04
Pick-Up	0	1	30
Standard (PD)	0	1	30
Sgl.Unit(Wrkr)	0	1	30
Cycle (PD)	0	1	30
Single Unit	0	1	30
Standard (PD)	0	1	30
Single Unit	0	1	30
Standard	0	1	28
Tractor	0	1	28
Standard	0	1	27
Standard	0	1	25
Sgl.Unit(Wrkr)	0	1	25
Standard (PD)	0	1	22

Type	Hr	Min	Sec
Standard	0	2	00
Standard	0	2	00
Standard	0	2	00
Standard	0	2	00
Standard (PD)	0	2	00
Standard	0	2	00
Cycle (PD)	0	2	00
Cycle (PD)	0	2	00
Panel	0	2	00
Compact	0	1	55
Standard	0	1	55
Compact	0	1	55
Standard	0	1	55
Standard (PD)	0	1	55
Single Unit	0	1	50
Standard	0	1	50
Foreign	0	1	48
Standard	0	1	45
Standard	0	1	45
Comb.	0	1	45
Pick-Up	0	1	45
Standard	0	1	45
Standard	0	1	45
Single Unit	0	1	45
Standard	0	1	45
Standard	0	1	45
Single Unit	0	1	45
Standard	0	1	40
Standard	0	1	40
Standard	0	1	40
Standard	0	1	40
Comb.	0	1	40
Single Unit	0	1	40
Standard	0	1	40
Standard (PD)	0	1	40
Panel	0	1	40
Standard	0	1	40
Standard	0	1	40
Single Unit	0	1	40
Single Unit	0	1	35
Sgl.Unit(Wrkr)	0	1	35
Comb.	0	1	35
Std. (WKMH)	0	1	33
Standard	0	1	31
Standard	0	1	30
Comb.	0	1	30
Std. (WKMH)	0	1	30
Standard	0	1	30
Standard	0	1	00
Standard	0	1	00
Standard	0	1	00
Panel	0	1	00
Standard	0	1	00
Standard	0	1	00
Cycle (PD)	0	1	00
Standard	0	1	00
Standard	0	1	00
Standard	0	1	00
Single Unit	0	1	00
Panel	0	1	00
Sgl.Unit(Wrkr)	0	1	00

May Weekdays (continued)

Type	Hr	Min	Sec
Standard	0	1	20
Cycle	0	1	20
Standard	0	1	20
Standard	0	1	20
Standard	0	1	15
Panel	0	1	15
Standard	0	1	15
Standard	0	1	15
Standard	0	1	15
Standard	0	1	15
Standard	0	1	15
Panel	0	1	15
Comb.	0	1	15
Standard (WKMH)	0	1	15
Single Unit	0	1	15
Cycle	0	1	15
Standard	0	1	15
Cycle	0	1	15
Cycle (PD)	0	1	15
Standard	0	1	15
Single Unit	0	1	10
Standard	0	1	10
Standard	0	1	10
Standard (PD)	0	1	10
Single Unit	0	1	10
Sgl.Unit(Wrkr)	0	1	10
Standard	0	1	05
Standard	0	1	05
Standard	0	1	05
Single Unit	0	1	05
Standard	0	1	05
Standard	0	1	05
Standard	0	1	05
Standard	0	1	05
Standard	0	1	05
Sgl.Unit(Wrkr)	0	1	05
Standard	0	1	05
Standard	0	1	02
Comb.	0	1	00
Standard	0	0	40
Standard	0	0	40
Standard	0	0	40
Standard	0	0	40
Standard (PD)	0	0	40
Standard	0	0	40
Standard	0	0	40
Standard	0	0	40
Standard (PD)	0	0	40
Standard	0	0	40
Sgl.Unit(Wrkr)	0	0	35
Standard (PD)	0	0	35
Standard	0	0	35
Standard	0	0	35
Single Unit	0	0	35
Standard	0	0	35
Comb.	0	0	35
Standard	0	0	35
Panel	0	0	35
Standard (WKMH)	0	0	35
Standard	0	0	35
Standard	0	0	34
Pick-Up	0	0	33

Type	Hr	Min	Sec
Standard	0	1	00
Standard	0	1	00
Comb.	0	1	00
Cycle (PD)	0	1	00
Cycle (PD)	0	1	00
Standard	0	1	00
Pick-Up	0	1	00
Standard	0	0	55
Standard	0	0	55
Standard	0	0	55
Standard	0	0	55
Standard	0	0	55
Standard	0	0	53
Standard	0	0	50
Standard (PD)	0	0	50
Standard	0	0	50
Comb.	0	0	50
Standard	0	0	50
Standard	0	0	50
Standard (PD)	0	0	50
Standard (PD)	0	0	50
Standard	0	0	50
Comb.	0	0	50
Standard	0	0	50
Sgl.Unit(Wrkr)	0	0	45
Standard	0	0	45
Standard	0	0	45
Standard (PD)	0	0	45
Single Unit	0	0	45
Standard	0	0	45
Pick-Up	0	0	45
Standard	0	0	45
Single Unit	0	0	45
Standard	0	0	40
Single Unit	0	0	40
Standard	0	0	40
Standard	0	0	40
Standard	0	0	40
Pick-Up	0	0	40
Standard	0	0	20
Standard	0	0	20
Standard	0	0	15
Standard	0	0	15
Standard	0	0	15
Standard	0	0	15
Standard	0	0	12
Standard	0	0	10
Pick-Up	0	0	10
Comb.	0	0	09

May Weekdays (continued)

Type	Hr	Min	Sec	Type	Hr	Min	Sec
Pick-Up	0	0	32				
Standard	0	0	30				
Standard	0	0	30				
Standard (PD)	0	0	30				
Sgl.Unit (Van)	0	0	30				
Standard	0	0	30				
Standard	0	0	30				
Standard	0	0	30				
Standard	0	0	30				
Standard (WKMH)	0	0	30				
Standard	0	0	30				
Standard	0	0	30				
Pick-Up	0	0	30				
Foreign	0	0	30				
Standard	0	0	30				
Comb.	0	0	30				
Single Unit	0	0	30				
Standard	0	0	30				
Single Unit	0	0	25				
Standard	0	0	25				
Standard	0	0	25				
Standard	0	0	25				
Standard	0	0	20				
Standard	0	0	20				
Single Unit	0	0	20				

May Weekend

Type	Hr	Min	Sec	Type	Hr	Min	Sec
Comb.	19	6	30	Standard	0	3	40
Standard	7	19	50	Standard (PD)	0	3	40
Standard	3	22	35	Standard	0	3	30
Standard	2	2	45	Standard (PD)	0	3	27
Standard	1	42	00	Standard (PD)	0	3	15
Standard	1	10	35	Standard (PD)	0	3	15
Standard	1	10	10	Standard (PD)	0	3	13
Standard	1	10	0	Standard (PD)	0	3	00
Standard	1	8	43	Sgl.Unit(WCRC)	0	2	53
Standard	1	6	30	Standard	0	2	50
Standard	0	57	45	Standard (PD)	0	2	30
Sgl.Unit(Wrkr)	0	48	30	Standard (PD)	0	2	30
Standard	0	29	30	Standard (PD)	0	2	30
Standard	0	22	15	Standard (PD)	0	2	30
Standard	0	22	15	Standard (PD)	0	2	10
Panel/Pick-Up	0	18	45	Panel/Pick-Up	0	2	10
Standard	0	18	40	Standard (PD)	0	2	10
Standard	0	17	30	Cycle (PD)	0	2	00
Standard	0	17	30	Standard (PD)	0	2	00
Standard	0	15	45	Cycle (PD)	0	2	00
Standard	0	15	30	Sgl.Unit (WCRC)	0	2	00
Standard	0	14	0	Standard	0	1	30
Standard	0	13	32	Standard	0	1	30
Standard	0	13	20	Standard	0	1	25
Standard	0	13	20	Standard	0	1	05
Standard	0	12	45	Standard	0	1	05
Standard	0	12	0	Standard	0	1	00
Standard	0	12	0	Standard	0	1	00
Standard	0	11	30	Standard	0	1	00
Standard	0	10	5	Standard	0	0	55
Sgl.Unit(Wrkr)	0	9	35	Standard	0	0	55

May Weekend (continued)

Type	Hr	Min	Sec	Type	Hr	Min	Sec
Standard	0	9	30	Standard	0	0	50
Sgl.Unit(Wrkr)	0	9	10	Standard (PD)	0	0	50
Sgl.Unit(Wrkr)	0	7	30	Cycle (PD)	0	0	50
Standard	0	7	15	Standard	0	0	50
Standard	0	7	0	Standard	0	0	45
Standard	0	6	50	Standard	0	0	45
Standard (PD)	0	6	50	Standard	0	0	45
Standard (PD)	0	6	30	Single Unit	0	0	45
Sgl.Unit(Wrkr)	0	5	31	Pick-Up	0	0	40
Standard	0	5	10	Standard	0	0	40
Cycle (PD)	0	5	0	Standard	0	0	38
Standard	0	4	50	Standard	0	0	35
Standard	0	4	50	Standard	0	0	35
Standard (PD)	0	4	50	Standard	0	0	33
Standard	0	4	35	Standard (PD)	0	0	30
Standard	0	4	20	Standard	0	0	25
Standard	0	4	20	Standard	0	0	21
Panel/Pick-Up	0	4	20	Small	0	0	20
Cycle (PD)	0	4	20	Standard	0	0	18
Standard	0	3	45				
Standard	0	3	45				

August Weekdays

Type	Hr	Min	Sec	Type	Hr	Min	Sec
Standard	4	43	40	Single Unit	0	7	15
Pick-Up	2	28	20	Comb.	0	7	10
Standard	1	38	55	Standard	0	7	00
Single Unit	1	26	55	Standard	0	6	50
Standard	0	57	00	Standard	0	6	10
Standard	0	51	00	Cycle (PD)	0	6	10
Standard	0	43	05	Standard	0	6	00
Single Unit	0	38	45	Standard (PD)	0	6	00
Standard	0	37	00	Standard	0	5	50
Standard	0	33	10	Standard	0	5	50
Standard	0	31	00	Standard	0	5	45
Panel	0	28	30	Sgl.Unit(WCRC)	0	5	30
Standard (WKMH)	0	27	05	Cycle (PD)	0	5	25
Standard	0	26	00	Standard	0	5	20
Pick-Up	0	23	50	Standard (PD)	0	5	20
Standard	0	23	40	Standard	0	5	15
Standard	0	23	30	Standard	0	5	10
Standard	0	23	30	Single Unit	0	5	10
Standard	0	21	00	Sgl.Unit (WCRC)	0	5	10
Standard	0	20	00	Standard (PD)	0	5	00
Standard	0	17	50	Standard	0	5	00
Sgl.Unit(Wrkr)	0	17	30	Foreign	0	5	00
Standard	0	16	00	Standard	0	5	00
Sgl.Unit(Wrkr)	0	16	00	Standard	0	4	50
Standard	0	15	20	Sgl.Unit(WCRC)	0	4	50
Standard (PD)	0	14	15	Cycle (PD)	0	4	45
Standard	0	14	10	Standard (PD)	0	4	32
Pick-Up	0	14	00	Cycle (PD)	0	4	25
Standard	0	14	00	Standard	0	4	25
Foreign	0	13	50	Standard (PD)	0	4	20
Standard	0	13	50	Standard (WKMH)	0	4	10
Standard	0	12	05	Standard	0	4	05
Standard	0	12	00	Standard (WKMH)	0	4	05
Standard	0	12	00	Standard (PD)	0	4	05
Standard	0	11	50	Standard (PD)	0	4	00

August Weekdays (continued)

Type	Hr	Min	Sec
Standard	0	11	42
Standard	0	11	30
Standard	0	11	15
Pick-Up	0	11	00
Sgl.Unit(Wrkr)	0	10	10
Standard	0	10	05
Standard	0	9	40
Standard	0	9	30
Cycle (PD)	0	9	20
Standard	0	9	05
Standard	0	8	15
Standard	0	7	55
Standard	0	7	45
Sgl.Unit(Wrkr)	0	7	35
Standard (WKMH)	0	7	20
Standard	0	7	20
Standard	0	7	20
Standard	0	3	00
Sgl.Unit(PLC)	0	2	55
Standard (PD)	0	2	51
Standard (WKMH)	0	2	50
Standard	0	2	50
Standard	0	2	50
Standard	0	2	45
Standard (WKMH)	0	2	40
Standard	0	2	40
Standard	0	2	35
Sgl.Unit(Wrkr)	0	2	35
Single Unit	0	2	30
Single Unit	0	2	30
Standard (WKMH)	0	2	30
Sgl.Unit(Wrkr)	0	2	30
Pick-Up	0	2	25
Standard (PD)	0	2	25
Standard (PD)	0	2	15
Standard	0	2	10
Standard	0	2	10
Pick-Up	0	2	08
Standard (PD)	0	2	07
Sgl.Unit(Wrkr)	0	2	05
Sgl.Unit(WCRC)	0	2	00
Standard	0	1	55
Standard (PD)	0	1	55
Single Unit	0	1	55
Standard	0	1	55
Standard	0	1	50
Single Unit	0	1	50
Single Unit	0	1	50
Standard	0	1	50
Standard	0	1	45
Standard	0	1	45
Standard	0	1	45
Compact	0	1	40
Single Unit	0	1	40
Cycle (PD)	0	1	40
Standard	0	1	40
Standard	0	1	40
Single Unit	0	1	35
Standard	0	1	35
Single Unit	0	1	30
Standard (WKMH)	0	1	30
Standard	0	1	30
Standard	0	4	00
Standard	0	4	00
Standard	0	4	00
Standard	0	3	45
Standard	0	3	35
Standard	0	3	30
Sgl.Unit(Wrkr)	0	3	30
Standard	0	3	30
Standard	0	3	16
Sgl.Unit(Bell)	0	3	15
Comb.	0	3	15
Standard	0	3	05
Single Unit	0	3	00
Standard	0	3	00
Single Unit	0	3	00
Standard	0	3	00
Standard (PD)	0	3	00
Compact	0	1	15
Sgl.Unit (WCRC)	0	1	15
Single Unit	0	1	15
Standard	0	1	10
Standard	0	1	10
Standard	0	1	10
Standard	0	1	10
Standard	0	1	10
Standard	0	1	05
Comb.	0	1	05
Sgl.Unit(WCRC)	0	1	05
Foreign	0	1	05
Standard	0	1	05
Standard	0	1	05
Standard	0	1	00
Single Unit	0	1	00
Standard (PD)	0	1	00
Standard	0	1	00
Single Unit	0	1	00
Standard(WKMH)	0	0	58
Standard	0	0	55
Single Unit	0	0	50
Standard	0	0	50
Small	0	0	50
Standard	0	0	45
Standard	0	0	45
Standard	0	0	45
Standard	0	0	40
Single Unit	0	0	40
Standard (WKMH)	0	0	40
Standard (PD)	0	0	40
Cycle (PD)	0	0	40
Single Unit	0	0	40
Standard	0	0	40
Pick-Up	0	0	40
Standard	0	0	40
Single Unit	0	0	35
Standard	0	0	35
Standard	0	0	35
Sgl.Unit(WCRC)	0	0	35
Standard (PD)	0	0	35
Standard	0	0	30
Standard	0	0	30
Standard	0	0	30
Standard (PD)	0	0	30

August Weekdays (continued)

Type	Hr	Min	Sec	Type	Hr	Min	Sec
Standard	0	1	30	Standard	0	0	25
Standard	0	1	30	Standard	0	0	20
Standard (PD)	0	1	30	Standard	0	0	20
Standard	0	1	25	Standard	0	0	20
Single Unit	0	1	23	Panel	0	0	20
Sgl.Unit(Wrkr)	0	1	20	Standard	0	0	20
Standard	0	1	20	Sgl.Unit(Wrkr)	0	0	20
Single Unit	0	1	20	Standard	0	0	15
Cycle	0	1	20	Standard	0	0	15
Standard	0	1	20	Standard	0	0	12
Standard	0	1	15	Standard	0	0	10

Accidents and Operational Characteristics on Arterial Streets with Two-Way Median Left-Turn Lanes

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The need to expedite through traffic and still provide adequate access to abutting properties resulted in the installation of the first two-way median left-turn lane (2WLTL) by the City of Seattle Traffic Engineering Division in November 1952. Since that time more than twelve 2WLTL's have been installed.

Brief studies conducted by the Division indicated that the 2WLTL's facilitate the movement of through traffic and provide a high degree of access service, yet their use has not resulted in an increase in traffic accidents.

Because the 2WLTL appears to be a useful and effective tool to the traffic engineer, and because its use is not very widespread, it was felt that a detailed accident study on arterials utilizing 2WLTL's was in order as well as an operational study of the 2WLTL with respect to the volume and manner of vehicles using it.

This study considered the effect of the 2WLTL on accident experience along streets serving commercial and industrial areas. Trends in accidents, accident rates, type of motor-vehicle collisions, and accident severity were considered. The report indicates that proper use of the 2WLTL can aid in the reduction of accidents or at least help to attenuate increases in accidents when traffic volume and property development increase.

The 2WLTL is not an accident hazard by itself, because accidents involving the 2WLTL are few in number. Furthermore, although it may be used by traffic in opposing directions of travel, head-on accidents on it are virtually nil. Property damage and injury appear to be less severe for the 2WLTL than for non-2WLTL accidents.

The operations studies showed that the 2WLTL on the arterial through an industrial area was used by 3 percent of the traffic, but on the arterial adjacent to a shopping center and commercial development the 2WLTL was used by 23 percent of the traffic. This latter study also showed that a greater length of the 2WLTL was used for left-turn maneuvering during rush hours than off-peak hours, and that out-of-county drivers used substantially less length of the lane.

The observations showed a need for investigation into more effective signing and/or marking of the 2WLTL in order to insure its proper use by unfamiliar drivers.

In addition to providing for midblock and intersection left turns, the 2WLTL also provides for refuge and separation functions. In actual operation it is used for many of the emergency functions of a median shoulder area, including detour routes when utility cuts and street maintenance are necessary. The lane also allows for easier movement of emergency vehicles, particularly during peak hours.

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There are situations that require the use of a conventional median with unidirectional left-turn lanes. However, under certain conditions the 2WLTL may provide a better design in terms of traffic service and economy of construction.

• THE uncontrolled left turn is closely related to the problems of highway safety and the facilitation of through-traffic flow. The attempted solution to the problems caused by vehicles turning left usually has been either the partial or complete prohibition of left turns or some form of median control and/or channelization of left-turn lanes. However, there are situations where these practices do not offer a satisfactory solution to the problem. Recognizing this fact, the Traffic Engineering Division of Seattle evolved a new method for dealing with left-turn traffic, the two-way median left-turn lane (2WLTL). A 2WLTL consists of a median area delineated only by paint lines and/ or traffic buttons, which may be used by traffic in either direction for making left turns. Left turns may be made from any point along the 2WLTL. Such an installation should not be confused with the conventional, unidirectional median utilizing left-turn lanes where prohibited areas are set off with raised barriers, dividers, or paint lines (Fig. 1A).

The major function of a 2WLTL is to provide a deceleration and storage lane for left turns to minor generators, including both legal streets and abutting properties. Secondary functions of the 2WLTL are the separation of opposing traffic flows, an acceleration lane for vehicles turning left onto the arterial from minor streets and abutting properties, a pedestrian refuge, and an emergency lane for breakdowns or for use by emergency vehicles.

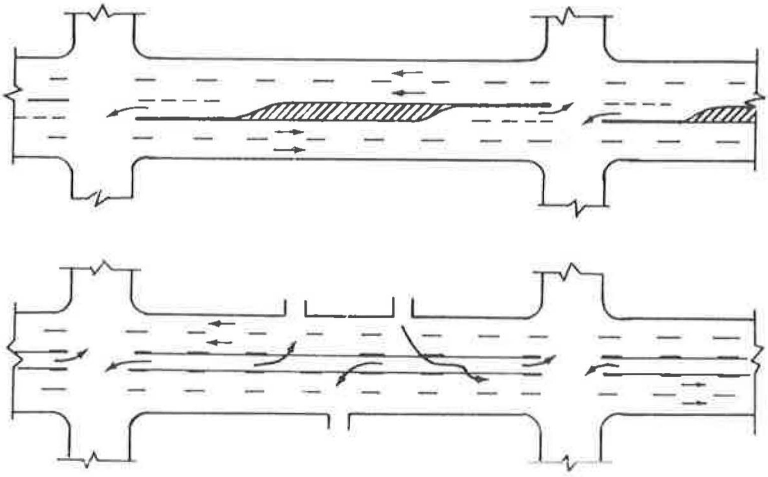
The 2WLTL has been used in Seattle in order to reduce accidents and delay on arterial streets traversing areas where several or all of the following conditions exist: (a) high-volume multilane streets; (b) strip commercial and/or industrial development of small individual vehicle generation; (c) a lack of, or inadequate, cross and parallel streets for around-the-block movements; and (d) adequate distance between arterial intersections.

In many cases the conventional median with left-turn lanes is most desirable. A 2WLTL might be more satisfactory, however, where there is a need for providing access to abutting property from both directions, but the pattern of the locations of the driveways leading to and from the off-street parking areas makes the conventional raised median (or a median with prohibited areas designated by paint lines) impractical. Such would be the case, for example, along a street with various commercial, industrial, or professional buildings with their own off-street parking areas; the parking entrances and exits being staggered so that they are neither uniformly located or closely spaced along the street. A conventional median with openings to provide for this situation would present a rather confusing pattern to the motorist.

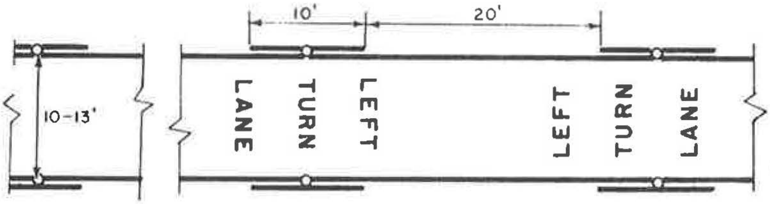
Another possible use of the 2WLTL might be in a situation where cross streets are rather far apart, or there are no parallel streets and midblock left turns from through lanes are undesirable. In this instance, an excessive amount of travel and delay is created by around-the-block movements needed to effect the left turn.

Another condition for use of the 2WLTL would be an arterial with frequent cross streets and streets parallel to the arterial traverse areas where high traffic volumes are undesirable, such as schools, hospitals, or single-dwelling residential areas. The cross and parallel streets may also be substandard with respect to the handling of large commercial vehicles.

Adequate signing and marking of the 2WLTL are necessary in order to insure proper use of the facility and minimize confusion to out-of-town drivers and other motorists not familiar with the 2WLTL. Several signing methods for 2WLTL's have been used by the Seattle Traffic Engineering Division: (a) overhead signs installed on span wire, 18 by 18 in., double-faced with the legend, "TWO WAY LEFT TURN LANE"; and (b) post-mounted signs, 2 by 3 ft, placed about 2 ft above the pavement in medial island areas bearing the legend, "BEGIN TWO WAY LEFT TURN LANE" (these signs are subject to repeated damage unless placed with proper clearance in raised traffic islands). In addition, all installations have "LEFT TURN LANE" painted on the medi-



A. Conventional median with unidirectional left-turn lanes (upper figure) and a two-way median left-turn lane (lower figure).



B. Paint striping and legend for two-way median left-turn lane.

Figure 1. Conventional unidirectional left-turn lane and two-way median left-turn lane.

an lane and facing both directions. The 2WLTL is bounded by solid lines painted parallel to dashed lines. Spherical traffic buttons $2\frac{3}{4}$ in. high and 12 in. in diameter are placed on 40- to 80-ft centers on both double paint lines—latest standard is 100-ft spacing (Fig. 1B).

The clear width of the median lane should be 10 to 13 ft.

Installations of the 2WLTL in Seattle are shown in Figures 2, 3, 4, and 5. The major uses are in strip industrial and commercial areas and on arterials serving shopping centers (Figs. 2 and 3). Many installations have been made by converting arterials with 6 narrow lanes to streets with 4 wider through lanes and the 2WLTL. In some cases, curb parking was prohibited in order to provide wider through lanes and the 2WLTL.

Figure 4 shows before-and-after views of a 2WLTL installation on an arterial serving an outlying shopping center. At the bottom, the existing inside lane to the right of the center line has been marked off as the 2WLTL and the shoulder has been paved over to become the new outside lane. However, many of the 2WLTL's have been added without constructing new lanes. Ordinarily, installation of a 2WLTL costs less than construction of a series of unidirectional left-turn lanes.

Figure 5 shows examples of signing and marking for the 2WLTL. Figure 5A shows the signs placed at the beginning and end. These signs have also been used when the

1st Ave. S.

East Marginal Way

15th Ave. W.

N.W. Market St.

Figure 2. 2WLTL installations serving industrial and commercial areas.

2WLTL is interrupted by a unidirectional left-turn lane. The signs are set in small medial islands demarcated by traffic buttons. They are less likely to sustain damage, however, when placed on raised islands as in Figure 5B. Paint marking and button placement for the lane are shown in 5C. Note the use of the legend, "LEFT TURN LANE." This legend is always placed in a back-to-back manner so that it can be read from both directions of travel.

Sacramento County, Calif., which made some use of the 2WLTL, uses somewhat different methods of signing and marking (1).

Figure 3. 2WLTL installation serving a boating marina and beach area.

ACCIDENT STUDY

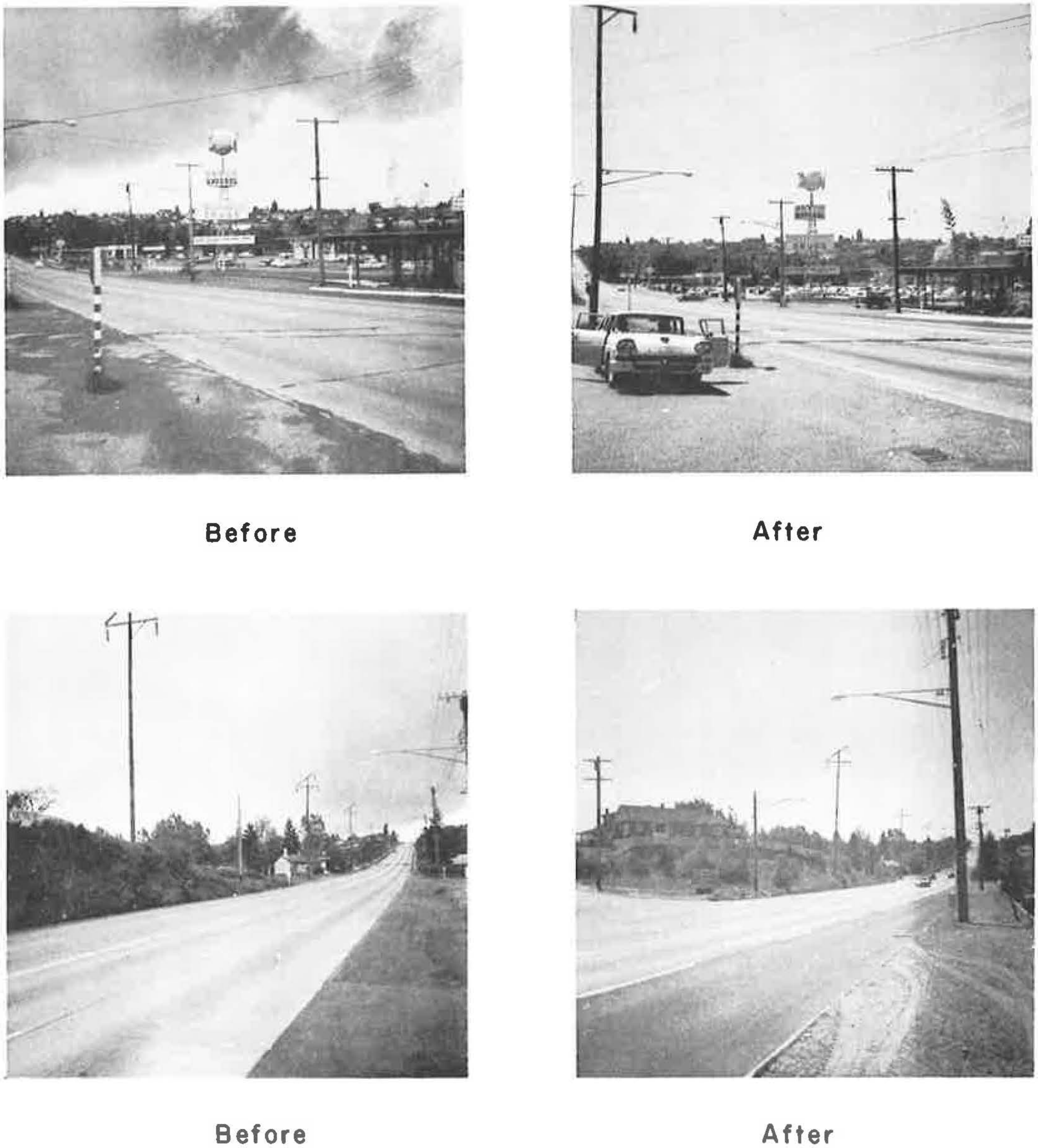
The major purpose of this investigation was to study and compare the number, types, and severity of accidents occurring on sections of arterial streets before and after the installation of 2WLTL's.

Site Selection

It was deemed desirable to study only those installations where a minimum of change in traffic volume, traffic control, or adjacent land use had occurred for some time before and after the installation of the 2WLTL. In this way the effect of the 2WLTL itself on traffic accidents could be better determined. A second criterion of site selection was that accident data be available for several years before as well as after the installation. The danger of drawing conclusions from a one-year before-and-after study is appreciated when one considers the following situation: Suppose that one-year before-and-after studies of a certain traffic-control measure show a 15 percent decrease in accidents after one year's use. Although this may seem to be a significant change, it loses its significance when further investigation shows that for several years before installation, the annual number of accidents had been decreasing at the rate of 15 to 20 percent per year. A third criterion was that the 2WLTL be of sufficient length. A relatively fewer total number of accident occurrences on one-and two-block 2WLTL's precluded their use.

From more than a dozen 2WLTL installations, two were selected for detailed accident analysis, and a third site was chosen for a study of only those accidents involving the use of the 2WLTL. The two installations selected for detailed study were those on Airport Way and 4th Avenue South. These 2WLTL sites are located in the industrial area of Seattle where various light and heavy industrial plants, warehouses, and trucking terminals are located. A part of the area served by these streets and close-ups of the streets and typical establishments located along them are shown in Figures 6 and 7. Characteristics of these installations are given in Table 1.

All cross streets along Airport Way and 4th Ave. S. are dead-ended by railroad tracks, except for two cross streets. Airport Way also lies beside a steel hill (Fig. 6B). Thus around-the-block movements cannot be used to effect left turns, making the use of a 2WLTL highly desirable. Fourth Ave. S. originally had a raised median varying from $2\frac{1}{2}$ to 5 ft in width (slightly wider where unidirectional left-turn lanes were located) before the 2WLTL was installed. There were median openings at intersections and also a few midblock openings. Sketches of sections of Airport Way and 4th Ave. S. both before and after installation of the 2WLTL are shown in Figure 8. A unidirectional left-turn lane was added at each of the two major intersections on Airport



Before After

Before After

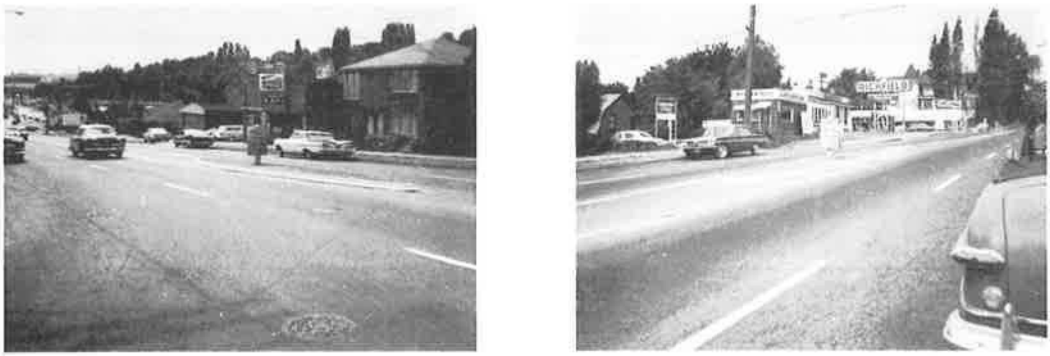
Figure 4. 2WLTL installations serving an outlying shopping center.

Way when the 2WLTL was installed and four unidirectional left-turn lanes were maintained at two intersections on 4th Ave. S.

Volume flow rates for Airport Way and 4th Ave. S. are shown in Figs. 9 and 10, respectively. The weekday traffic volume pattern is essentially constant along the two 2WLTL installations. Peak-hour volumes on these two arterials are approximately 2,500 vehicles. A 16-hr vehicular classification count for Airport Way is given in Table 2. The percentages of various commercial vehicles are similar on 4th Ave. S.

Airport Way satisfies all three criteria of study-site selection. Fourth Ave. S., however, does not fulfill the one requirement of several years' accident experience after installation of the 2WLTL. However, it was believed that a study of the 4th Ave. S. site was worthwhile, and that the study could be updated after several more years of experience.

A



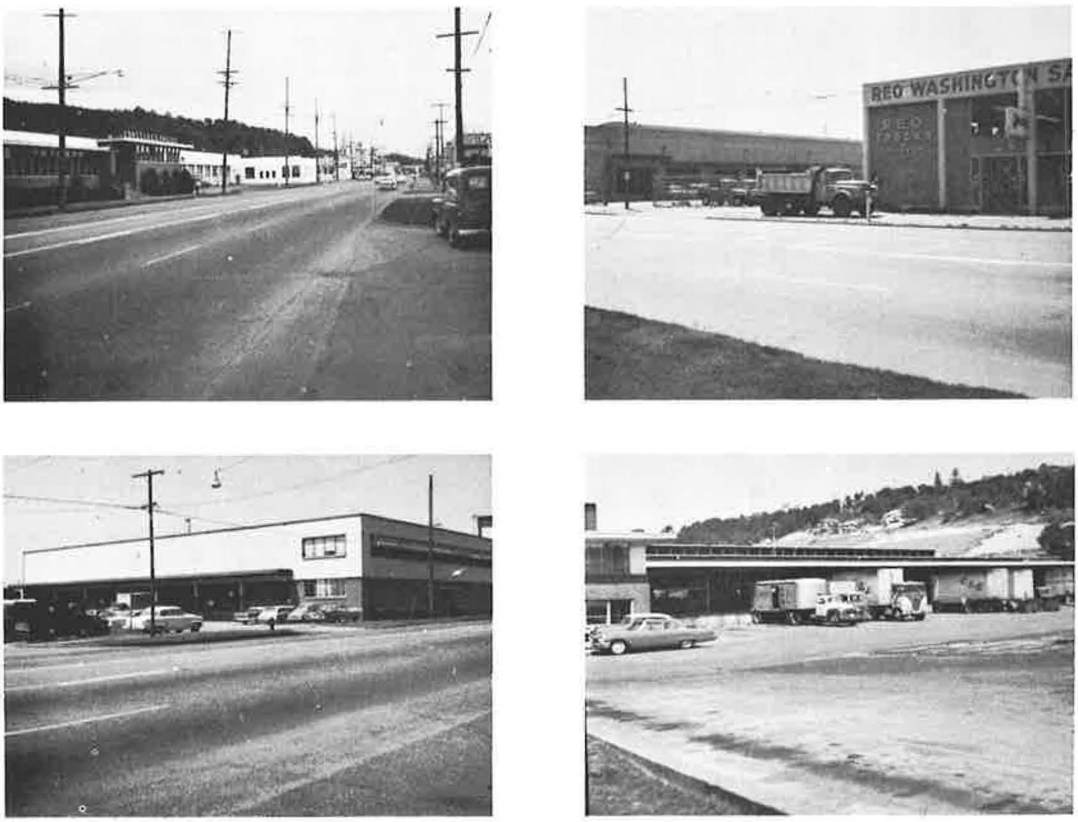
B

C

Figure 5. Signing and marking for 2WLTL installations.

A 2WLTL installation on 25th Ave. N. E. (Fig. 7B) was selected for studying only those accidents directly involving the 2WLTL. Because this street was widened from 2 to 5 lanes after installation of the 2WLTL, and because many new generators have been built since the installation, this street could not be used for a detailed before and after accident study. However, the various generators along the 2WLTL section (community shopping center, motels, apartments, filling stations) produce a high usage of the 2WLTL and an attendant greater number of 2WLTL accidents than on Airport Way and 4th Ave. S. This installation was also used in a study of certain operational charac-

A. Area served by Airport Way and 4th Ave. S. 2WLTL'S.



B. Typical generators along Airport Way.

Figure 6. 2WLTL sites used in accident study.

teristics of 2WLTL usage. A section of 25th N. E. is shown in Figure 8, and the volume flow rate in Figure 11. Peak-hour traffic volume on 25th N. E. is approximately

TABLE 1

2WLTL CHARACTERISTICS

Street	Total Length (mi)	Length[1] (mi)	Install. Date	Speed Limit (mph)	1962 ADT	Street Width (ft)	No. of Lanes[2]	Lane Widths[3] (ft)	Parking	Signing	Traffic Movement
Airport Way	1.03	0.95	10/20/58	30	20,900	58	5	11 #2WLTL, 11 and 12 thru	No		2-way progression
4th Ave. S.	1.49	1.31	6/28/61	35	27,500	82	8	12 #2WLTL, 10 and 11 thru	Yes	Sign islands and paint legends	Platoon movement, not progressed
25th Ave. N.E.	0.46	0.42	10/5/59	30	15,800	54	3[4]	12 #2WLTL, 10 and 11 thru	Yes[5]		No signals

[1] Excluding unidirectional left-turn lanes.
[2] Including 2WLTL.
[3] Clear.
[4] Five during peak hours.
[5] None during rush hours.

1,500 vph. Other characteristics of the 2WLTL site are given in Table 1.

Two additional 2WLTL installations were studied briefly. These sites, located along high-volume radials, Aurora Ave. N. and Bothell Way, serve commercial land uses. The sites did not meet the requirement of minimum change in land use intensity and other requirements necessary for a detailed study of the effect of the 2WLTL on traffic accidents.

Accident Data

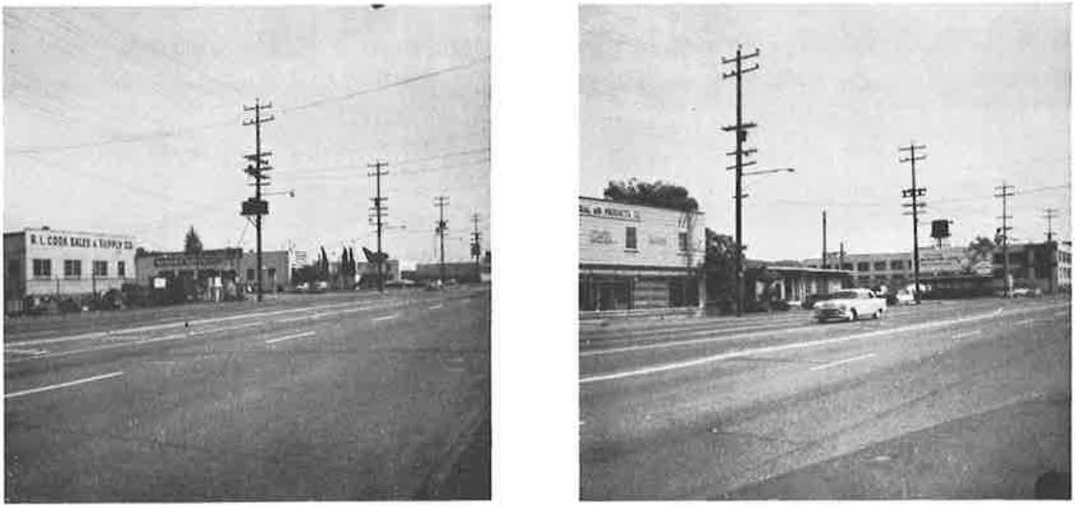
All accident data were taken from copies of the original accident reports filed by the motorists and kept by the Traffic Engineering Division and Police Department. Items recorded for each accident were day and date, location of accident, collision type, injury and injury severity, total property damage, whether the accident involved the 2WLTL, and whether drivers involved were local or out-of-towners.

General collision types are diagramed in Figure 12. The types are head-on, rear-end, left-turn, angle, sideswipe, and "other". The collision types also apply generally to accidents involving the 2WLTL. Potential 2WLTL collisions are shown in Figure 12B.

Injury severity has four degrees. Fatality is severity one; visible signs of injury such as a bleeding wound, distorted member, or having to carry the injured from the scene of the accident is severity two; other visible injuries such as bruises, abrasions, swelling, or limping is severity three; and no visible injury but complaint of pain or momentary unconsciousness is severity four.

Property damage was determined as the sum of the estimated costs to repair the vehicles involved plus damage to property such as fire hydrants, signs, and buildings. This sum was rounded to the nearest $50. If an accident was investigated by an officer, the total property damage was determined as the sum of his estimations rather than those of the drivers involved in the accident. If an accident was not investigated by an officer, the total property damage was determined as the sum of each individual's estimate of the cost to repair his own vehicle. Although many drivers tend to overestimate their own damage somewhat, it has been assumed that this is unimportant when property damage is compared in a relative manner, such as from year to year.

In addition to the determination of property damage, the severity of injury and the



A. 4th Ave. S.

B. 25th Ave. N.E.

Figure 7. 2WLTL sites used in accident study.

type of collision were based on the police officer's report when available.

Original accident reports were available only since the start of 1956. In that year, 21.4 percent of the accidents on Airport Way were investigated with the percentages generally increasing to date. Table 3 gives the percentages for both Airport Way and 4th Ave. S.

GENERAL ACCIDENT TRENDS

Airport Way

Accidents on Airport Way were studied for four years before and three years after the installation of the 2WLTL. Accident data for the first six months of the fourth year

TABLE 2

16-HOUR TOTALS FOR WEEKDAY VEHICULAR CLASSIFICATION COUNT 6:00 AM TO 10:00 PM ON AIRPORT WAY

Vehicle Type	No. of Vehicles[1]	% of All Vehicles	% of Trucks and Buses	Subtotals (%)
Autos[2]	18,757	88.4	-	-
Trucks and buses:				
Total	2,474	11.6	100	100
Single unit:				
SU-2	1,404	6.6	56.8	61.0
SU-3	104	0.5	4.2	
Buses	278	1.3	11.2	11.2
Semi's:				
2-S-1	212	1.0	8.6	23.3
2-S-2	121	0.6	4.9	
3-5-2	243	1.1	9.8	
Full trailer combinations:				
Semi with full trailer	49	0.2	2.0	4.5
Single unit with trailer:				
2-2	7	-	0.3	
3-2	56	0.3	2.2	

[1] Total vehicles: 21,231.
[2] Light trucks without dual tires classed as autos.

after installation were expanded to a full year, thereby giving four years of before and after experience. For this reason, the fourth year after study is shown by a dashed line in the pertinent figures.

Table 4 summarizes the accidents on Airport Way each year with respect to collision types and total accidents. The data from this table have been plotted in Figures 13 and 14. Before installation of the 2WLTL, the total accidents per year were in the range of 60 to 70. There was a moderate increase in accidents during the first year after installation (12.6), a phenomenon not uncommon when new traffic-control measures are installed. The following years show a sharp drop to the level of about 45 accidents per year. Figure 13 shows that a reduction in rear-end accidents accounted for most of the drop, with the other types of collision being fairly constant in number over the years and showing no general trends.

To consider the effects of traffic volume on accident experience, average weekday volumes were obtained and plotted (Fig. 15). Volume over the years of study fluctuates somewhat, but shows no general upward or downward trend. When these volumes are applied to the weekday accidents, the curves in Figure 16 result. Total weekday accidents do not include Saturday and Sunday. Accidents per million vehicles have been used rather than accidents per million vehicle miles because the former is a measure of accident probability (2). Prior to the

TABLE 3

PERCENTAGE OF REPORTED ACCIDENTS INVESTIGATED BY POLICE OFFICER

Year	Airport Way[1]	4th Ave. S.[2]
56-57	21.4	-
57-58	37.2	-
58-59	40.0	41.8
59-60	37.2	45.1
60-61	54.6	46.4
61-62	52.5[3]	54.5

[1] Yearly intervals: Nov. through Oct.
[2] Yearly intervals: July through June.
[3] Estimated.

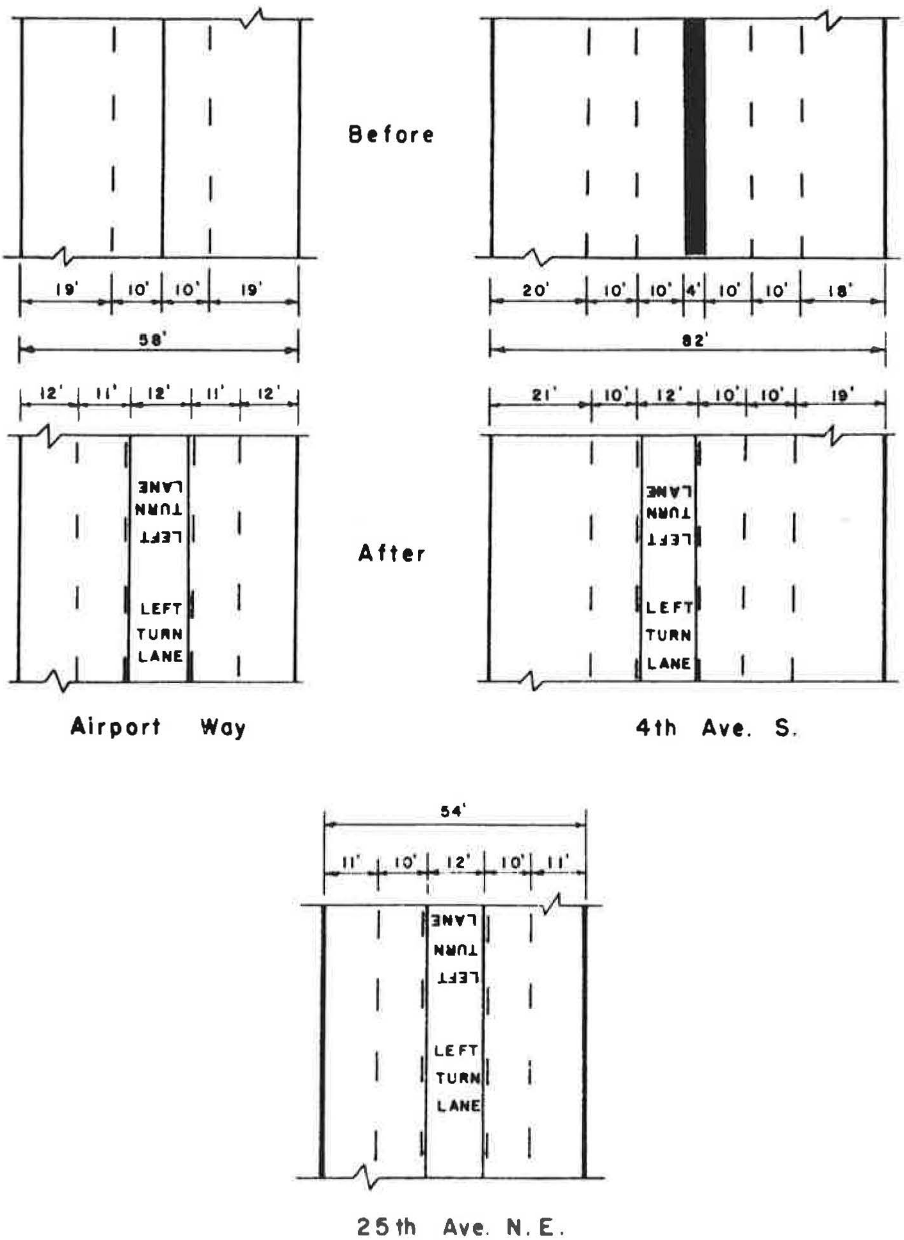


Figure 8. Laning on Airport Way, 4th Ave. S. and 25th Ave. N. E.

installation of the 2WLTL, the weekday accidents seem to be fairly constant each year, but when the study is based on traffic volume, a slight downward trend in accidents appears during these years. This downward trend makes the reduction in accidents in the second, third, and fourth year after installation somewhat less spectacular. Figure 17 shows the volume-based accident rate for weekday rear-end accidents.

Figure 18 shows a comparison of total accidents per year on Airport Way with the total of the reported accidents for the entire city of Seattle (when accidents or other measures of accident experience are given on a yearly basis, the yearly basis is in terms of full years before or after installation of the 2WLTL, and not coinciding with

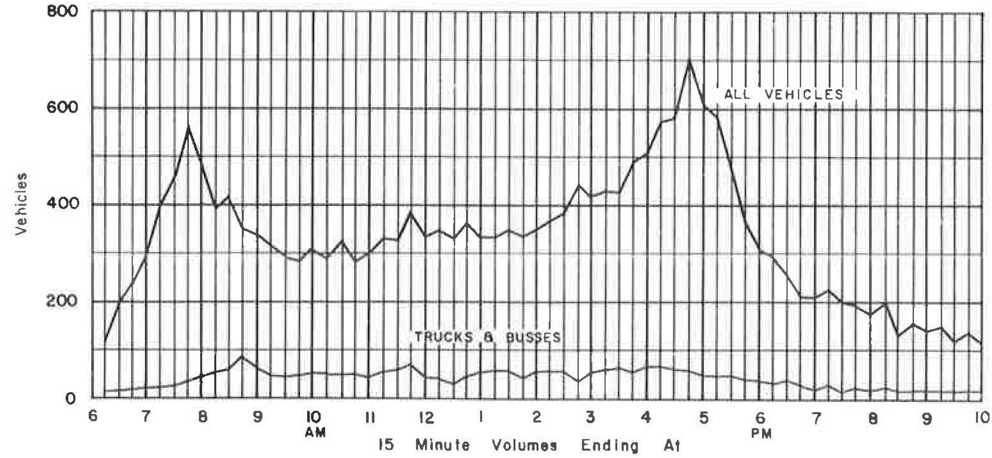


Figure 9. Typical weekday volume variation on Airport Way, 1962.

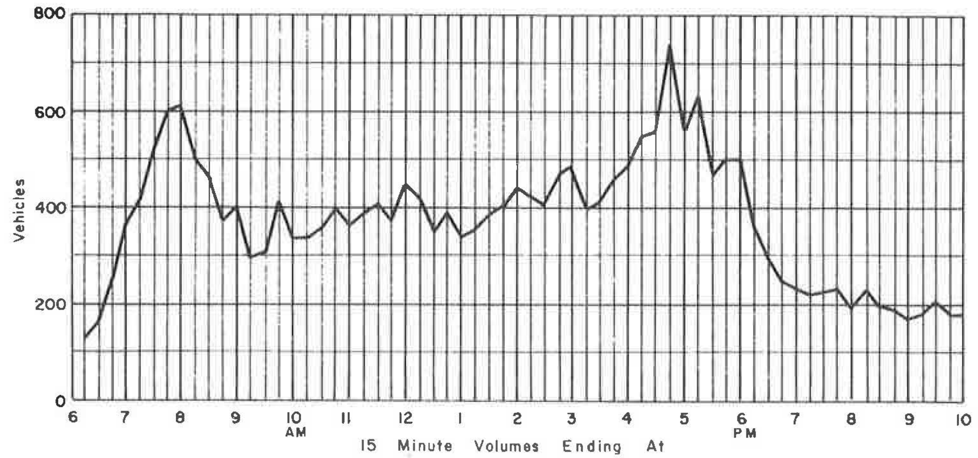


Figure 10. Typical weekday volume variation on 4th Ave. S., 1962.

TABLE 4

SUMMARY OF AIRPORT WAY ACCIDENTS BY TYPE OF COLLISION

Type of Collision	Years Before 2WLTL Installation								Years After 2WLTL Installation							
	4		3		2		1		1		2		3		4[1]	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Rear end	36	58.2	39	53.5	38	54.3	37	59.6	46	65.7	18	41.8	27	61.3	17	42.5
Sideswipe	10	16.1	16	21.9	18	25.7	9	14.5	7	10.0	6	13.9	3	6.8	9	22.5
Angle	3	4.8	5	6.8	9	12.8	6	9.7	9	12.9	9	21.0	6	13.6	3	7.5
Left turn	3	4.8	1	1.4	1	1.4	0	0	4	5.7	1	2.3	4	9.1	3	5.0
Hit parked car	6	9.7	5	6.8	2	2.9	4	6.5	1	1.4	0	0	2	4.6	2	5.0
Other	4	6.4	7	9.6	2	2.9	6	9.7	3	4.3	9	21.0	2	4.6	7	17.5
Total	62	100.0	73	100.0	70	100.0	62	100.0	70	100.0	43	100.0	44	100.0	41	100.0

[1] Estimated on the basis of 6 months' experience.

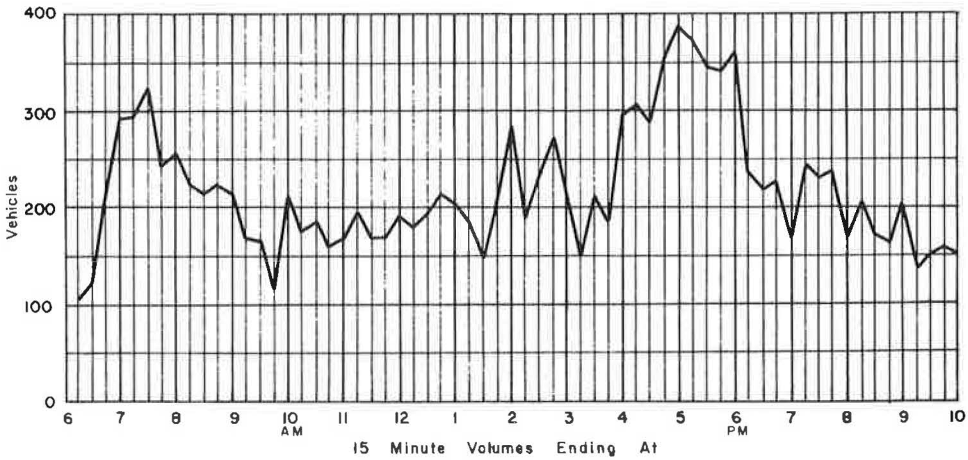


Figure 11. Typical weekday volume variation on 25th Ave. N. E., 1962.

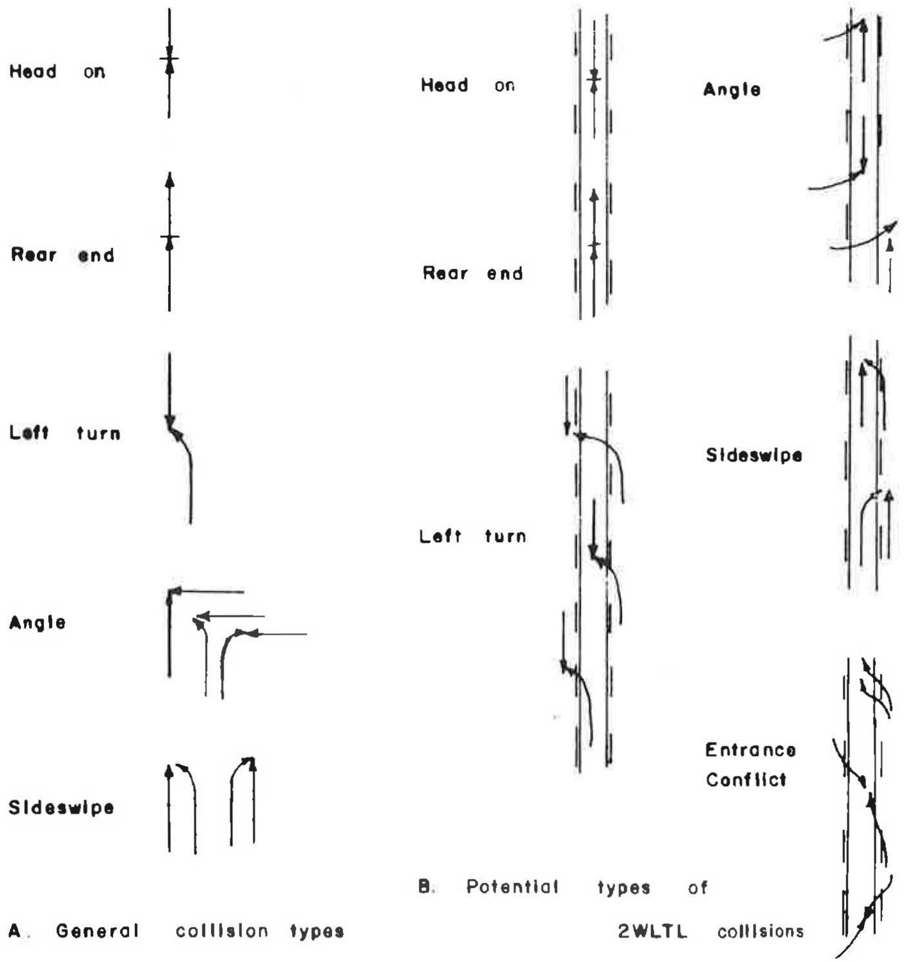


Figure 12. Collision types used in accident study.

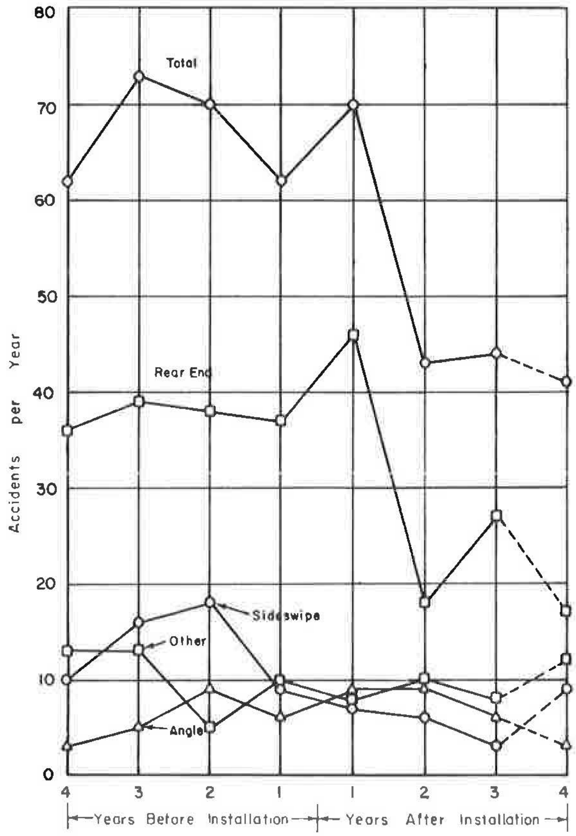


Figure 13. Accidents by collision type on Airport Way.

the calendar year). Figure 19 similarly represents rear-end accidents. Seattle accident experience shows a slight upward trend over the years. Accidents in Seattle for one year after are the highest, correlating with the rise in accidents during that year for Airport Way. Thus the rise in accidents on Airport Way during the first year of 2WLTL use may have been due not only to possible confusion about its proper use, but also to a generally higher level of accidents as a whole that year, possibly due to weather conditions.

The intent of this study is to determine not only the effect of the 2WLTL on the magnitude of accidents but also on their severity. For this reason, injury severity and the percent of accidents with injuries were studied (Fig. 20). It is important that the injury accidents appear to be decreasing during the after period. However, consideration should be given to the percent of accidents with injury that also reflects the decrease in total accidents (Fig. 18). There was no significant change in the degrees of injury severity. Figure 21 compares total injury accidents with weekday injury accidents and also weekday injury accidents per million weekday vehicles. There do not appear to be any definite trends after installation of the 2WLTL, except that the Saturday and Sunday injury accidents appear to have been reduced.

Figure 22 shows another measure of accident severity, property damage estimates. The high points are one year after, corresponding to the peak effect for the number of accidents for the year. Except for the first year, the total property damage appears to be decreasing slightly. The average property damage per accident rose somewhat after installation. It would seem that the accidents are somewhat more severe after installation of the 2WLTL, but considering the differences of 50 to 100 dollars per accident before and after plus the fact that property damage was rounded to the nearest 50 dollars,

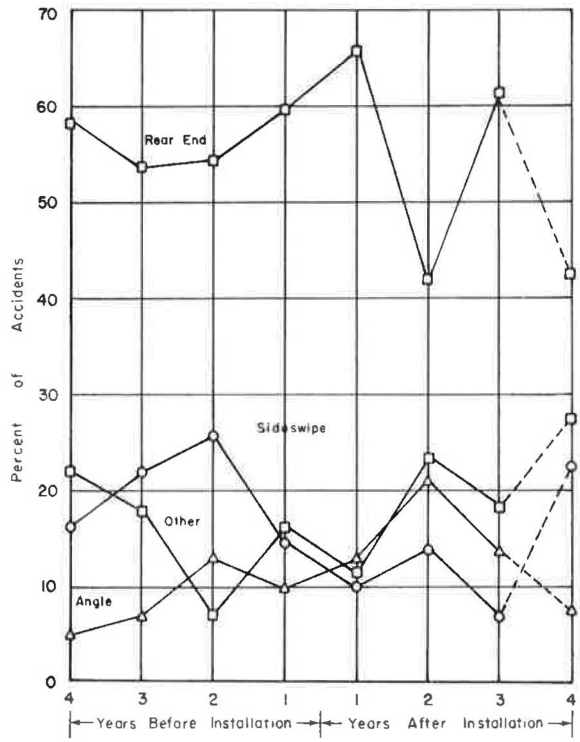


Figure 14. Percent accidents by collision type on Airport Way.

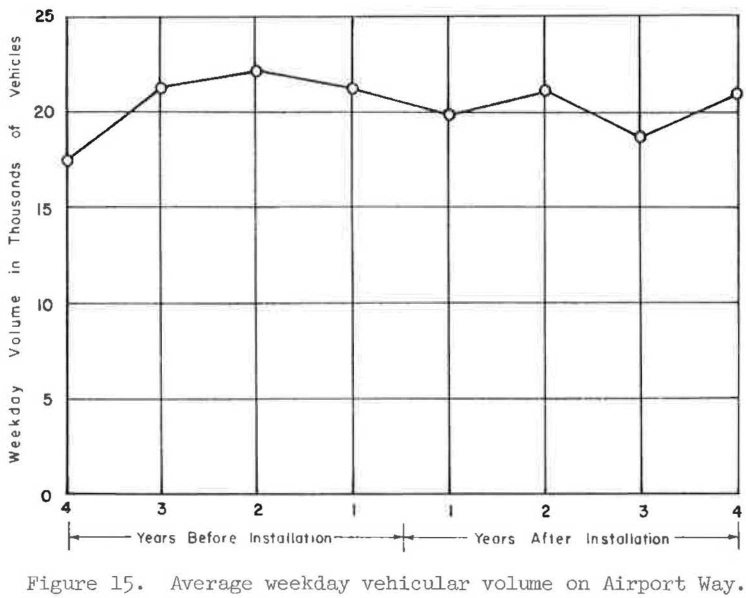


Figure 15. Average weekday vehicular volume on Airport Way.

this trend may not have any valid support for that conclusion. There is close correspondence between total accidents (Fig. 13) and total property damage.

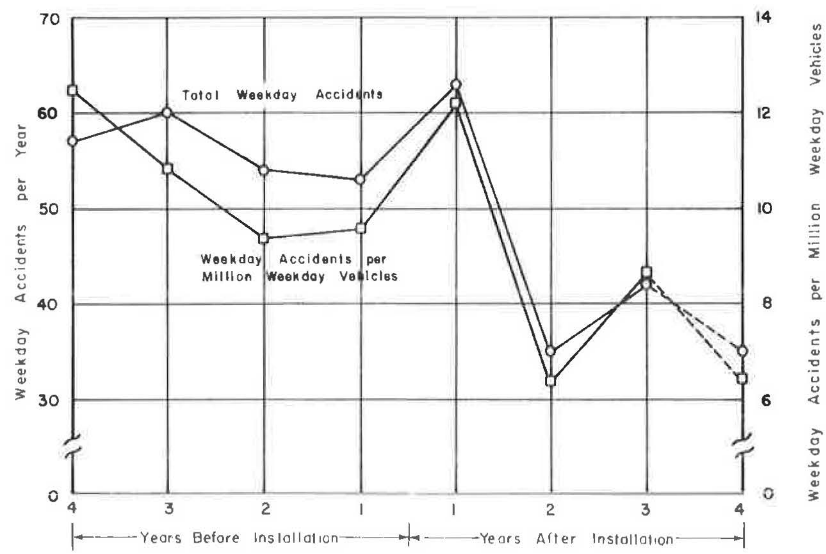


Figure 16. Weekday accidents and weekday accidents per million weekday vehicles on Airport Way.

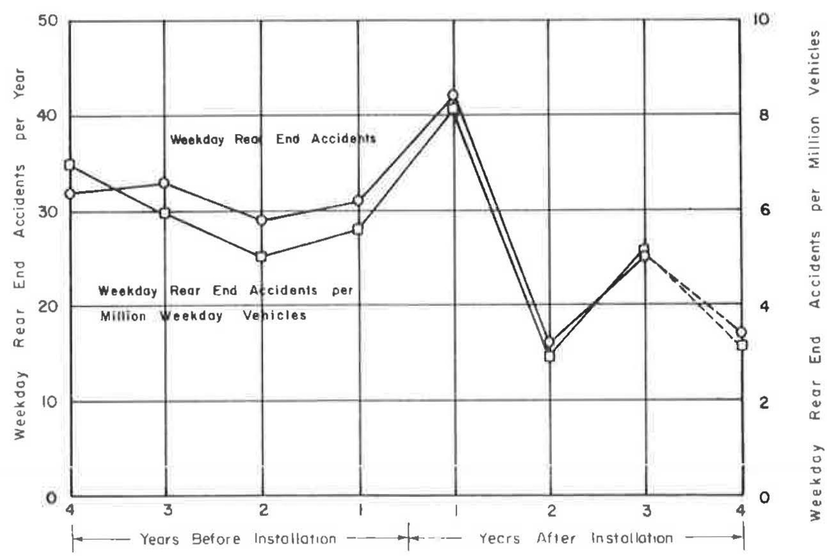


Figure 17. Weekday rear-end accidents and weekday rear-end accidents per million weekday vehicles on Airport Way.

A few words are in order on the problem of determining what percentage of the accident reduction on Airport Way was actually due to the installation of single unidirectional left-turn lanes for westbound traffic at the two major intersections along the study section. In general, accidents decreased along sections of the 2WLTL where the busiest generators existed, and in only one short section (less than a block long) did accidents increase. Apparently the installation of the 2WLTL was responsible for about 75 percent of the general reduction of accidents occurring in the interval after the one-year-after period. Furthermore, it is quite possible that the 2WLTL might

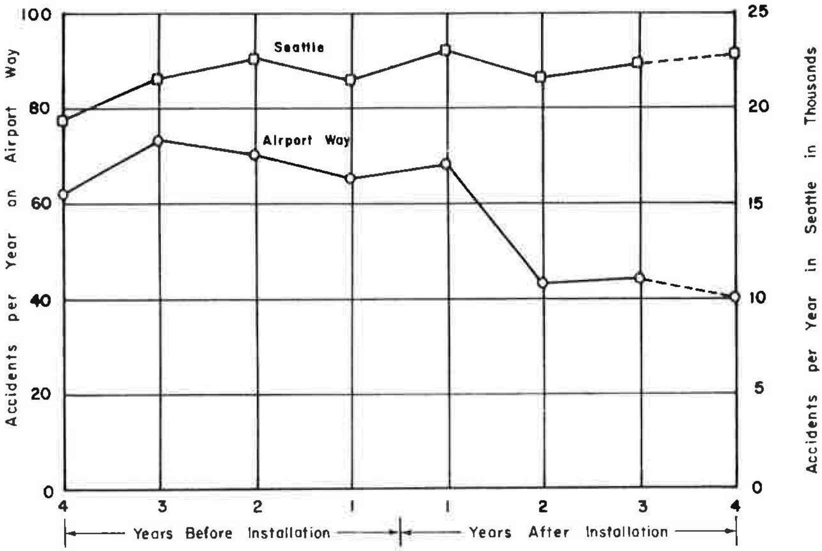


Figure 18. Comparison of total accidents in Seattle with total accidents on Airport Way.

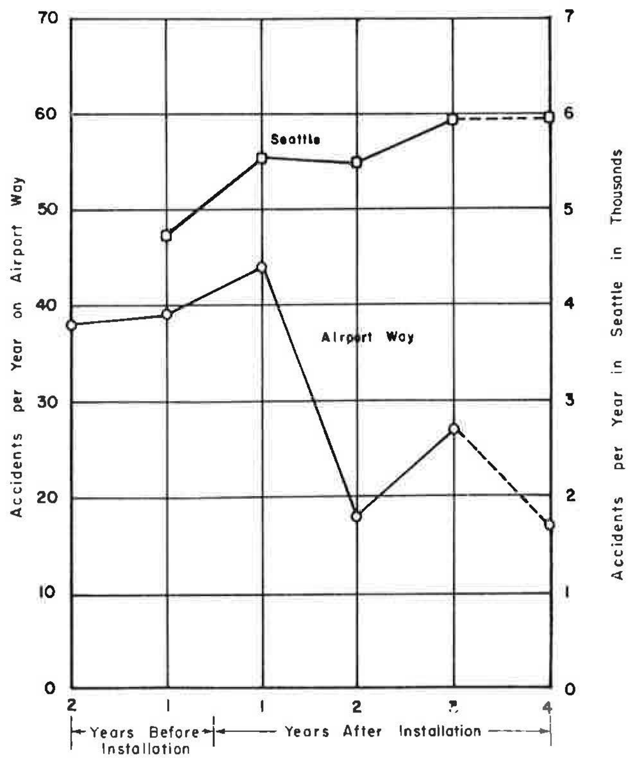


Figure 19. Comparison of total rear-end accidents in Seattle with rear-end accidents on Airport Way.

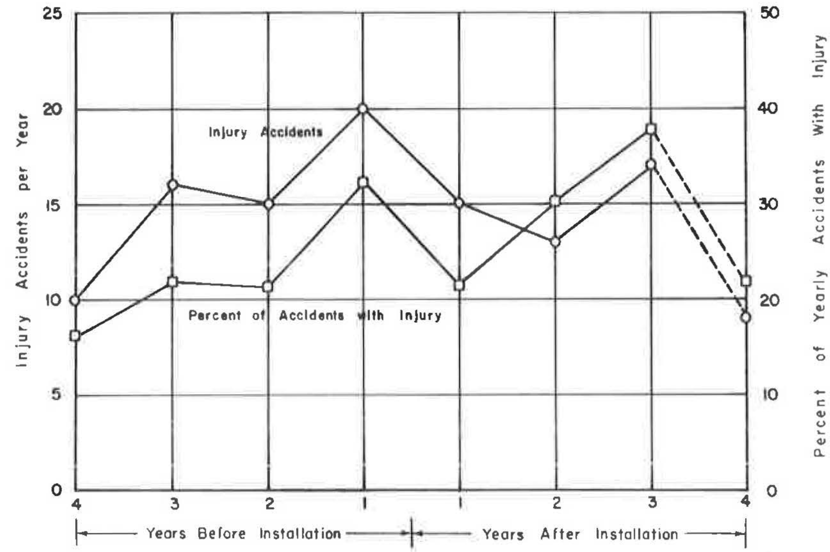


Figure 20. Injury accidents and percent of accidents with injury on Airport Way.

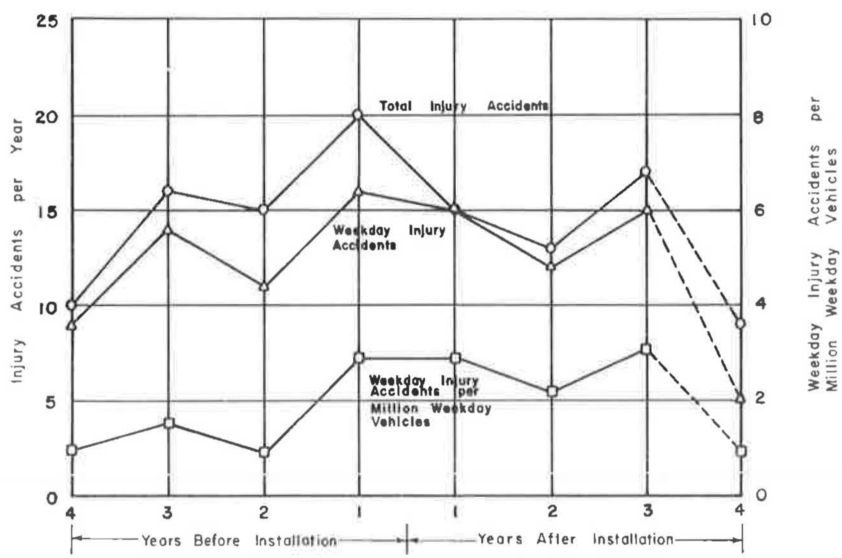


Figure 21. Total injury accidents, weekday injury accidents, and weekday injury per million weekday vehicles on Airport Way.

have served just as well as the conventional unidirectional left-turn lanes in terms of expediting traffic flow and reducing accidents.

4th Avenue S.

Traffic accidents on 4th Avenue S. were studied for three years before and one year after installation of the 2WLTL. The significance of accident trends on 4th Ave. S. is somewhat limited by the short after period. However, the one-year-after experience is valuable in comparison with Airport Way accident experience, since these two sites

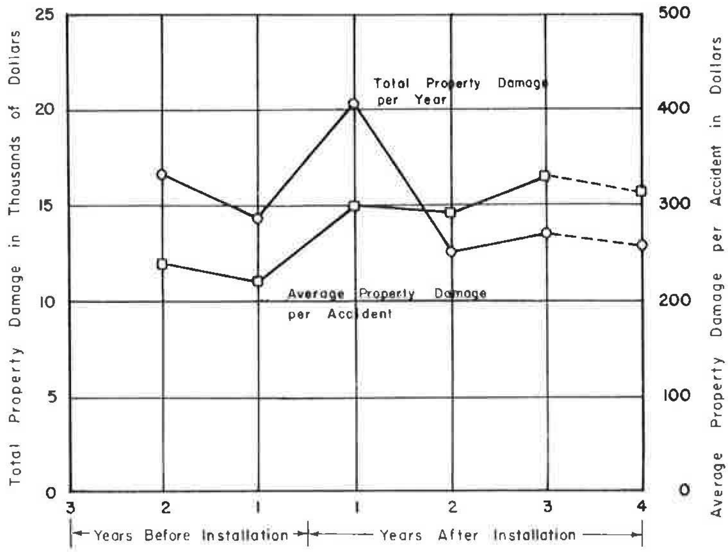


Figure 22. Total property damage per year and average property damage per accident on Airport Way.

TABLE 5

SUMMARY OF 4TH AVE. S. ACCIDENTS BY TYPE OF COLLISION

Collision Type	Years Before 2WLTL Installation						1 Year After 2WLTL Installation	
	3		2		1			
	No.	(%)	No.	(%)	No.	(%)	No.	(%)
Rear end	51	52.0	25	30.5	32	46.4	29	37.3
Sideswipe	22	22.4	17	20.7	12	17.4	14	17.9
Angle	4	4.1	18	22.0	5	7.2	15	19.2
Left turn	14	14.3	11	13.4	9	13.0	8	10.2
Other	7	7.2	11	13.4	11	16.0	12	15.4
Total	98	100.0	82	100.0	69	100.0	78	100.0

are very similar. In addition, this installation offered an opportunity to compare the 2WLTL with a previous conventional median installation. Finally, it is hoped that the 4th Ave. S. study will be updated after several more years of experience.

Collision types and total accidents are given in Table 5 and in Figures 23 and 24. In general, there was a downward trend in accidents before installation of the 2WLTL, but total accidents increased by 14.5 percent during the first year after installation, which also corresponds to a slight increase in volume during this year (Fig. 25). Comparing the total accidents in Figure 23 with volume in Figure 25, a close correlation exists between total accidents and average weekday traffic volume. When either weekday or total accidents are plotted against average weekday volume, a strong linear relationship results. On the other hand, a plot of Airport Way data shows virtually no correlation between traffic volume and accidents.

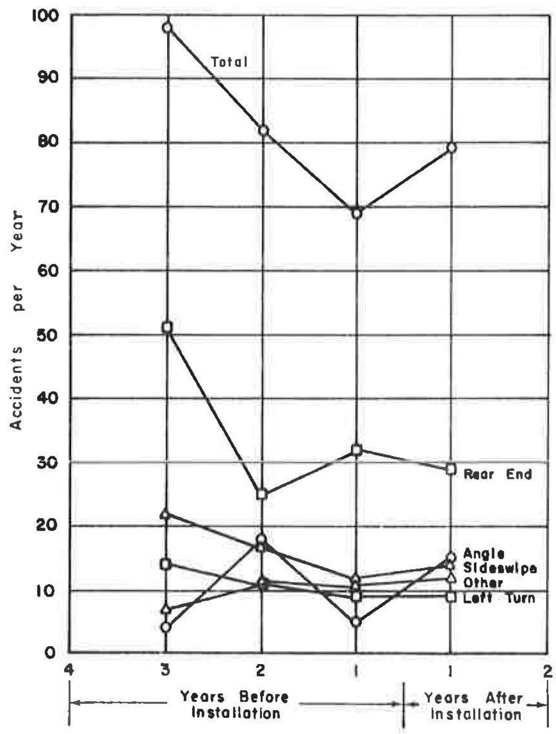


Figure 23. Accidents by collision type on 4th Ave. S.

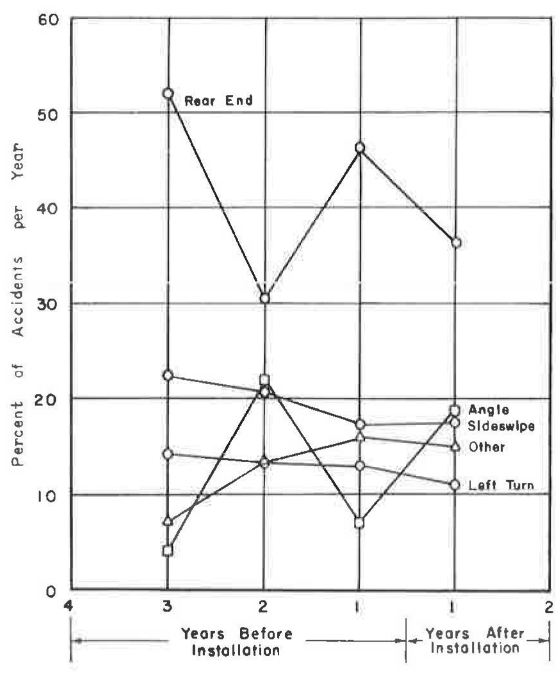


Figure 24. Percent accidents by collision type on 4th Ave. S.

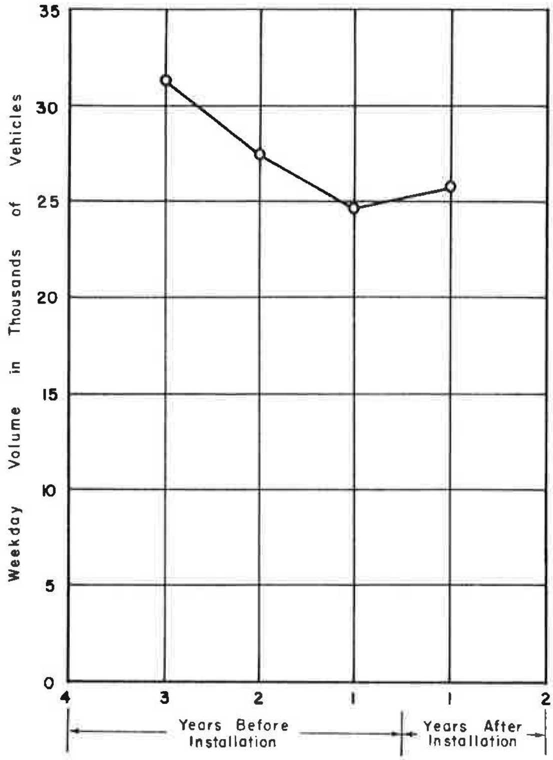


Figure 25. Average weekday vehicular volume on 4th Ave. S.

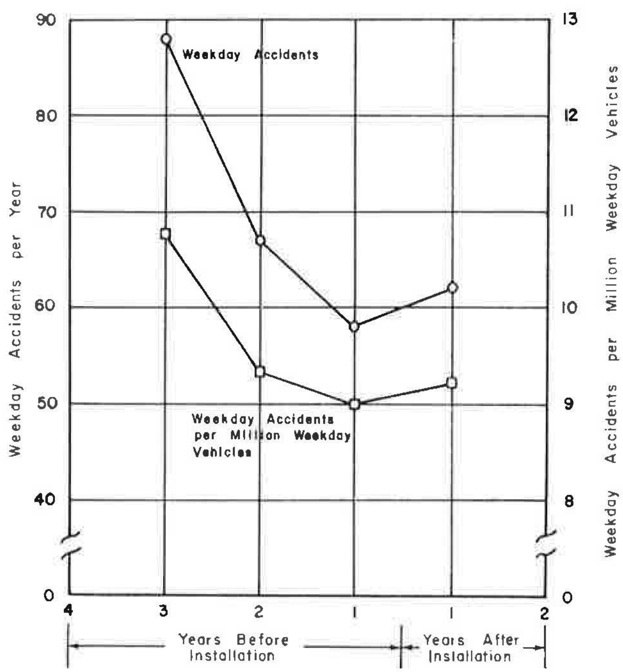


Figure 26. Weekday accidents and weekday accidents per million weekday vehicles on 4th Ave. S.

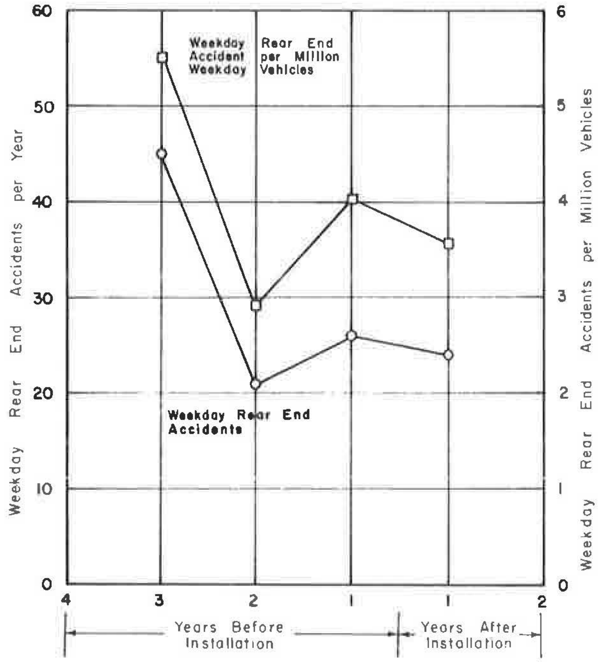


Figure 27. Weekday rear-end accidents and weekday rear-end accidents per million weekday vehicles on 4th Ave. S.

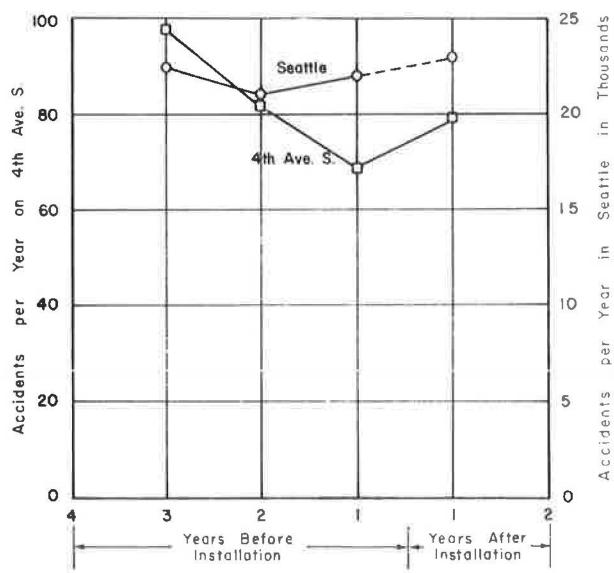


Figure 28. Comparison of total accidents in Seattle with total accidents on 4th Ave. S.

Volume-based accident rates for total weekday accidents and weekday rear-end accidents (Figs. 26 and 27) correspond rather closely to the related curves in Figure 23. Although Figures 28 and 29 show that total and rear-end accidents have been decreasing as compared to increases in Seattle accidents as a whole, the first year after shows a correspondence between Seattle and 4th Ave. S. data in terms of total and rear-end accidents.

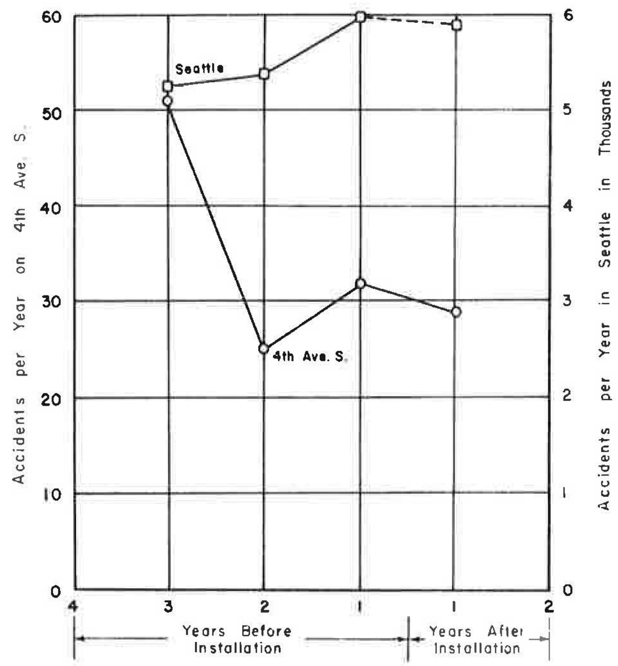


Figure 29. Comparison of total rear-end accidents in Seattle with rear-end accidents on 4th Ave. S.

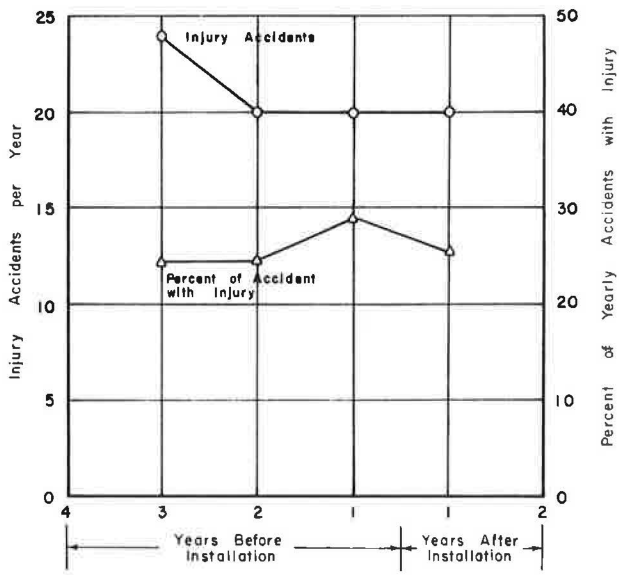


Figure 30. Injury accidents and percent of accidents with injury on 4th Ave. S.

Although injury accidents (Figure 30) showed no change during the one-year-after period, the percent of accidents with injury decreased slightly. Figure 31 shows that the downward trend in weekday injury accidents and weekday injury accidents per million weekday vehicles continued during the first year of 2WLTL use. This would seem

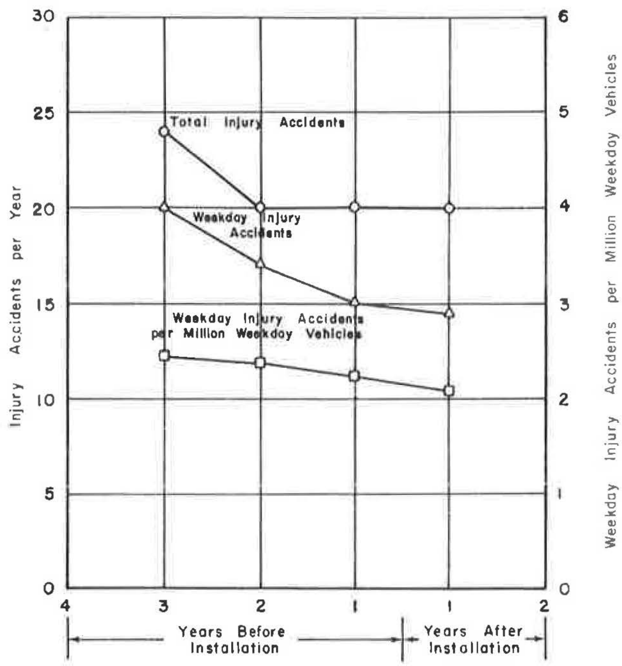


Figure 31. Total injury accidents, weekday injury accidents, and weekday injury accidents per million weekday vehicles on 4th Ave. S.

to indicate that the 2WLTL has little or no effect on accident severity. Considering total property damage as an index of accident severity (Fig. 32), accident severity apparently increased following the installation of the 2WLTL. It is evident, however, that total property damage corresponds rather closely to the total number of accidents, which a comparison of Figures 23 and 32 seems to indicate. Considering this relationship and the rather constant nature of the average-property-damage-per-accident curve, the 2WLTL installation did not really cause an increase in accident severity.

Except for the two major intersection areas, accidents were fairly evenly distributed over the study section. Although the overall number of accidents in the previous year increased during the first year of 2WLTL use, in some locations the accidents decreased. There was a decrease around the two major intersections served by conventional, channelized, unidirectional left-turn lanes both before and after the installation of the 2WLTL. There was also a decrease in accidents in a block-long segment of the study section where there are numerous driveways and where several midblock median openings had previously existed.

Inasmuch as the increase in the number of accidents during the first year of 2WLTL use was not large and apparently was primarily due to an increase in traffic volume, the 2WLTL in this instance seems to serve as well as a median with auxiliary lanes for left turns. There is no reason to believe that a 2WLTL cannot serve as an intersectional left-turn lane almost as well as a conventional left-turn lane in certain localities. Not only does it provide for midblock left-turns, but it also serves as an emergency lane. Vehicles have used the 2WLTL to bypass traffic accidents and stalled vehicles; this could not be done easily with a conventional raised median, even one with mountable curbs. Furthermore, there is the possibility that a 10- or 12-ft wide 2WLTL may serve as a better separator of opposing traffic streams than a narrow 2-ft median or separator. Initial construction and maintenance costs abetted by the ease of street cleaning and snow removal, may well favor the 2WLTL over the conventional median with unidirectional left-turn lanes where midblock left turns are necessary and other conditions of traffic are suitable.

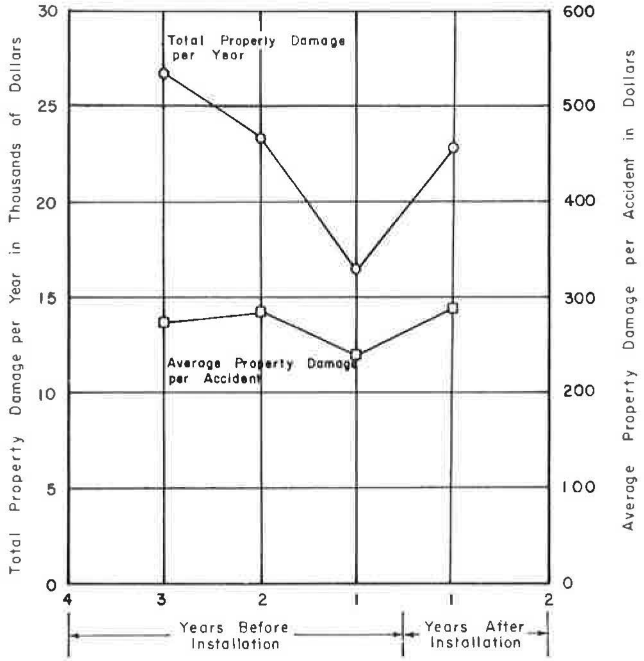


Figure 32. Total property damage per year and average property damage per accident on 4th Ave. S.

Aurora Avenue N. and Bothell Way

Two arterials with 2WLTL installations were studied briefly with respect to the total number of accidents each year. Changes in land use, traffic control, and pavement widths during the study period precluded a detailed study of the effect of the 2WLTL itself on accident experience.

Total accidents per year for both Aurora Ave. N. and Bothell Way are shown in Figure 33. These curves show the limitations of a one-year before-and-after study. Aurora Ave. N., for example, would show almost a 40 percent decrease in accidents with the first year of 2WLTL operation. The sharp increase in accidents during the one-year-before period, when compared with two, three, and four years before installation, along with the increase in accidents during the second-year-after period would be missed by the study.

Weekday traffic volume on Aurora increased from 29,000 vehicles per day during the fourth year prior to installation, to almost 36,000 vehicles per day the second year after installation. One could possibly get a better estimate of the effect of the 2WLTL on accident experience by neglecting the large increase and decrease in accidents one year before and one year after installation and studying, instead, the one year accidents occurring two years before and two years after. If the number of accidents during these one-year periods is divided by the corresponding average weekday traffic volume, a somewhat artificial and limited, yet nevertheless useful, index of accident experience is attained. These calculations yield values of 0.0038 and 0.0037 (weekday volume of 32,000 vehicles) and two years after (weekday volume of 35,000), respectively. Thus it appears that although the number of accidents has increased during the after period, the volume-based accident index has remained about the same. Considering the increases in traffic and increased property development along this arterial, the 2WLTL aids considerably in holding down the accident index.

Weekly traffic of 22,000 vehicles per day ± 1,000 vehicles per day was carried by Bothell Way (Fig. 33). Here, as in the case of the Aurora Ave. installation, a one-

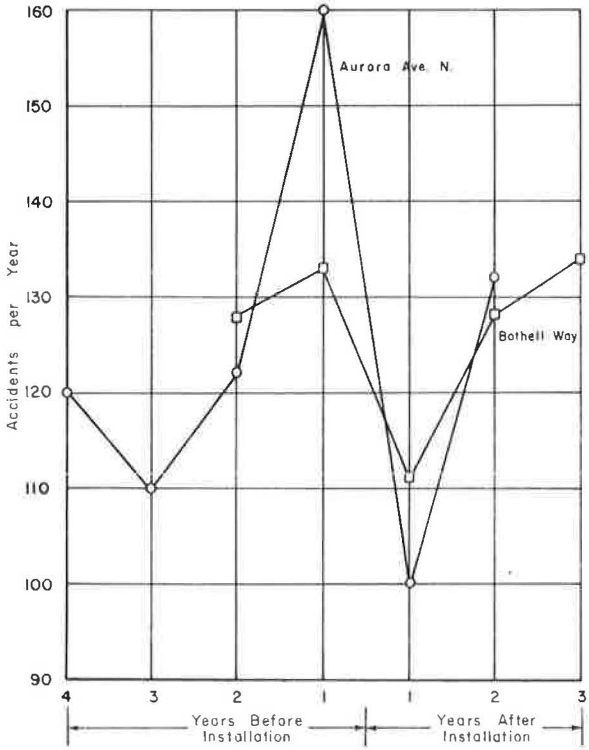


Figure 33. Accidents per year on Aurora Ave. N. and Bothell Way.

year before-and-after study presents a rosy picture in terms of accident reduction occurring with the installation of a 2WLTL. Except for one year after, the total number of reported accidents has held fairly steady at about 130 per year. Considering that traffic volume had been fairly constant for the years studied, it could be assumed that the 2WLTL did not bring about a reduction in the number of accidents. However, the severity of accidents has perhaps declined. It is speculated that on these two arterials during the first year after the installation, the 2WLTL served more as a median divider until the drivers became educated to its use for access purposes.

The preceding examples point out the limitations and pitfalls of trying to state definite conclusions and generalizations from a study of only one year before and after.

TABLE 6

NUMBER OF 2WLTL ACCIDENTS ON AIRPORT WAY

Years After Installation of 2WLTL	No. of 2WLTL Accidents	Percent of Total Accidents for the Year
1	5	7.3
2	2	4.7
3	0	0
4[1]	2	8.3
Total	9	—

[1] First six months of fourth year.

TWO-WAY LEFT-TURN LANE ACCIDENTS

Airport Way

Table 6 summarizes the 2WLTL accidents for Airport Way. These accidents are shown classified as to collision types in Table 7.

These accidents were distributed rather uniformly along the study section. Three of the nine accidents occurred dur-

TABLE 7

TYPES OF 2WLTL ACCIDENTS ON AIRPORT WAY[1]

Collision Type	No. of 2WLTL Accidents	Percent of 2WLTL Accidents
Rear end	1	11.2
Left turn	3	33.3
Angle	3	33.3
Sideswipe	2	22.2
Total	9	100.0

[1] $3\frac{1}{2}$ years experience.

TABLE 8

NUMBER OF 2WLTL ACCIDENTS ON 25TH AVE. N. E.

Years After Installation of 2WLTL	Number of 2WLTL Accidents	Percent of Total Accidents for the Year
1	5	23.8
2	6	28.6
3[1]	6	31.6
Total	17	–

[1] First six months of third year after only.

ing darkness, six during rush hours, and out-of-town drivers were involved in two. Furthermore, an out-of-town driver was at fault in only one of the accidents. There were no head-on collisions in the 2WLTL itself. Injuries occurred in two of the accidents. The small number of 2WLTL accidents does not allow a statistical comparison with non-2WLTL accidents in terms of severity (with injury accidents and property damage as indexes of severity).

There is no real indication that the number of 2WLTL accidents decreases each year as motorists become more familiar with the use of this method. Table 6 gives 5, 2, 0 and 4 (doubling the 1-month number to expand to a full year) 2WLTL accidents for 1, 2, 3 and 4 years after experience.

4th Ave. S.

The 4th Ave. S. 2WLTL installation was studied for one year after, and during that time four 2WLTL accidents occurred. There were two sideswipe collisions and one rear-end accident (caused by a vehicle backing into another waiting to turn left). The 2WLTL accidents represent 3.8 percent of the year's total. Three of the accidents occurred during darkness, one during rush hours, and injury occurred in only one.

25th Avenue N. E.

Table 8 summarizes the 2WLTL accidents for 25th Ave. N. E., which are classified as to collision types in Table 9.

The 2WLTL accidents on 25th Ave. N. E. represent 36 percent of all the accidents that occurred. This percentage is much higher than those for Airport Way and 4th Ave. S., but the 2WLTL usage is much higher at 25th N. E. than at those sites and the installation is relatively short in length (5 blocks long). Only 30 percent of the 2WLTL accidents occurred during rush hours, and 24 percent during darkness. Out-of-town drivers were involved in only one of the 17 2WLTL collisions, or 5.9 percent, while for non-2WLTL accidents during the same period, out-of-town drivers were involved in 12 of 44 accidents, or 27.2

TABLE 9

TYPES OF 2WLTL ACCIDENTS ON 25TH AVE. N. E.[1]

Collision Type	No. of 2WLTL Accidents	Percent of 2WLTL Accidents
Head on	1[2]	5.8
Rear end	2	11.8
Entrance conflict	2	11.8
Left turn	2	11.8
Angle	6	35.3
Sideswipe	4	23.5

[1] $2\frac{1}{2}$ years experience.
[2] Drunk.

TABLE 10

SUMMARY OF 2WLTL ACCIDENTS ON AIRPORT WAY, 4TH AVE. S. AND 25TH AVE. N. E.

Collision Type	No. of 2WLTL Accidents	Percent of 2WLTL Accidents
Angle	9	30.0
Sideswipe	8	26.7
Left turn	6	20.0
Rear end	4	13.3
Head on	1	3.3
Entrance conflict	2	6.7
Total	30	100.0

TABLE 11

VEHICULAR CLASSIFICATION FOR A 6:00 AM TO 10:00 PM WEEKDAY COUNT OF VEHICLES USING THE 2WLTL ON AIRPORT WAY

Vehicle Type	No. of Vehicles[1]	% of Vehicles[1]
Autos	336	45.7
Light trucks[2]	92	12.5
Single units	199	27.1
Combinations	108	14.7
Total	735	100.0

[1] To and from generators.
[2] Light commercial vehicles without dual wheels.

percent. Thus the out-of-town driver is responsible for but a small percentage of 2WLTL accidents.

Approximately two-thirds of the 2WLTL accidents occurred in the vicinity of three busy entrances to the large shopping center located along 25th Ave. N. E.

Summary of 2WLTL Accidents

The foregoing sections on 2WLTL accidents were presented in order to show the types that occur, and to make a comparison of their numbers with the total number of accidents. It is believed worthy of consideration since many traffic engineers probably do not wish to make use of the 2WLTL because they fear that its use will cause too many accidents. These engineers no doubt recall the high frequency of accidents on the 3-lane highways that were once prevalent.

Grouping the after-installation accident experience on Airport Way, 4th Ave. S., and 25th Ave. N. E., which represents 7 study years, there were 30 2WLTL accidents. This represents only 9.4 percent of the total number of accidents occurring at these installations. Considering this grouped experience further, 27.9 percent of the non-2WLTL accidents involved injuries, and injuries occurred in 23.3 percent of the 2WLTL accidents. The average property damage for the non-2WLTL accident was $328, and that for the 2WLTL accidents was $240. Although property damage is based on estimates rounded to the nearest $50, there seems to be some significance in the difference between these two values. Considering the above figures and those for injury accidents, it appears that the 2WLTL accident is somewhat less severe than the non-2WLTL accident. A summary of the collision types for the 2WLTL accidents is given in Table 10.

In general, there is no indication that the number of 2WLTL accidents decreases with use. Although one might expect this to occur, such a trend would be most likely postulated on the assumption of a somewhat high number of 2WLTL accidents during the first years of use. Such is not the case, however, for the number of 2WLTL accidents is relatively small, both in the early and later years of use.

OPERATIONAL CHARACTERISTICS

2WLTL Usage Volumes

Estimates of the volume of vehicles using 2WLTL's serving different types of land uses were thought desirable. Manual counts were made of the number of vehicles using the 2WLTL for left turns to generators from through lanes and left turns from genera-

TABLE 12

VEHICULAR CLASSIFICATION FOR A 7:15 TO 8:15 AM PEAK HOUR COUNT OF VEHICLES USING THE 2WLTL ON AIRPORT WAY

Vehicle Type	No. of Vehicles[1]	% of Vehicles[1]
Autos	52	69.3
Light trucks[2]	10	13.3
Single units	7	9.4
Combinations	6	8.0
Total	75	100.0

[1] To and from generators.
[2] Light commercial vehicles without dual wheels.

TABLE 13

VEHICULAR CLASSIFICATION FOR A 2:15 TO 3:15 PM PEAK HOUR COUNT OF VEHICLES USING THE 2WLTL ON AIRPORT WAY

Vehicle Type	No. of Vehicles[1]	% of Vehicles[1]
Autos	22	30.6
Light trucks[2]	16	22.2
Single units	24	33.3
Combinations	10	13.9
Total	72	100.0

[1] To and from generators.
[2] Light commercial vehicles without dual wheels.

tors and into the through lanes. A usage or 2WLTL movement, then is essentially a crossing of the 2WLTL when making a left turn to or from a generator.

Figure 34 shows a 16-hr record of weekday 2WLTL usage on a typical portion of the 2WLTL on Airport Way. This section is approximately 450 ft long, representing roughly 8 percent of the total 2WLTL length. It is bordered by 8 generators. The morning peak hour of usage primarily represents the arrival of workers to their places of employment. The majority of the usage at other times during the day is by commercial vehicles (ranging from 50 to 90 percent of the total vehicles using the 2WLTL and a 16-hr percentage of 54.3). During the afternoon peak hour of usage, 69.4 percent of the 2WLTL movements were made by commercial vehicles (Tables 11, 12 and 13). During the 16-hr count, 417 vehicles made turns to generators and 318 made turns from generators. The 16-hr 2WLTL usage volume represents 3 percent of the 16-hr total volume.

A 12-hr 2WLTL usage count (9:00 AM to 9:00 PM) was made at the 25th Ave. N. E. installation to determine the magnitude of 2WLTL movements in a commercial area. All the 2WLTL movements along a 600-ft portion of the 2WLTL were counted. This section, comprising about 25 percent of the total 2WLTL length, is bounded by the larger traffic generators in the area. The majority of the movements were those made to and from the several entrances to a community shopping center located off 25th Ave. N. E. Hourly usage of the 2WLTL is shown in Figure 35. Although to generator movements were approximately equal to from generator movements in Figure 34 for Airport Way, the to generator movements are nearly twice the from generator movements throughout the day for 25th Ave. N. E. Other shopping center access points are more convenient to exit from. The rise in 2WLTL usage at 9:00 PM is due to the fact that retail businesses were open until 9:00 PM on the day the count was made, and the rise represents the departure of shoppers and some employees.

During the 12-hr count, 2,494 vehicles used the 2WLTL; 846 traveling from generators and 1,648 moving to generators. The peak hour of usage occurred from noon to 1:00 AM, with 232 2WLTL movements. Throughout the day, automobiles accounted for approximately 90 percent of the 2WLTL usage. The 12-hr 2WLTL volume represents roughly 23 percent of the 12-hr total volume.

Maneuvers

This phase of the operations study was conducted to determine some of the driving characteristics exhibited by motorists using the 2WLTL. There is no doubt that proper use of the 2WLTL can aid in the reduction of accidents, reduce vehicular delay, and in general, expedite the flow of through traffic. The use of the 2WLTL requires no new

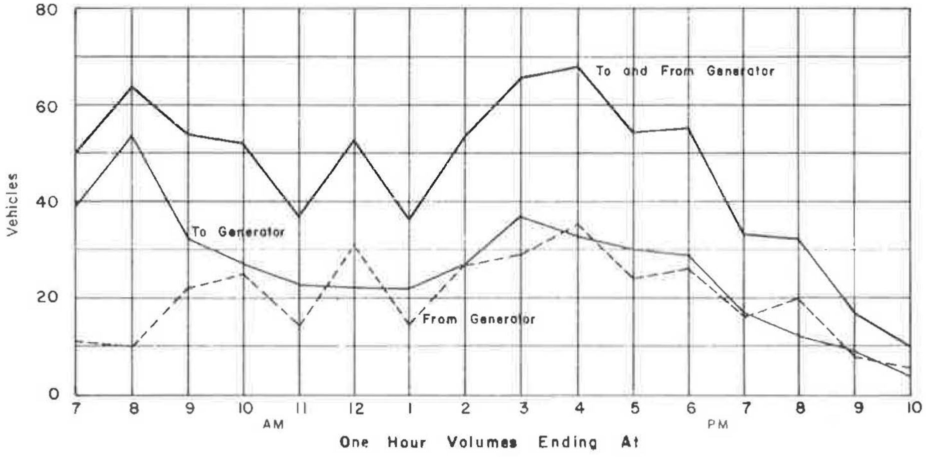


Figure 34. Weekday 2WLTL usage on Airport Way, 1962.

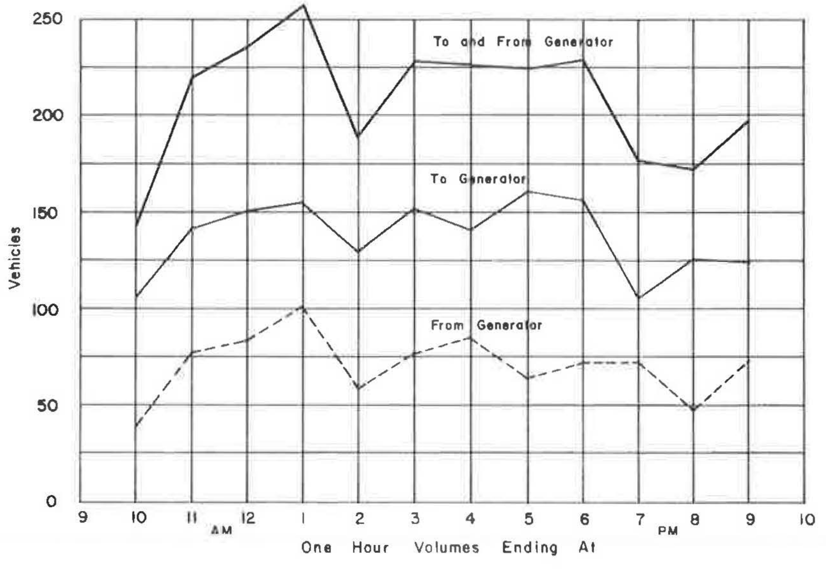
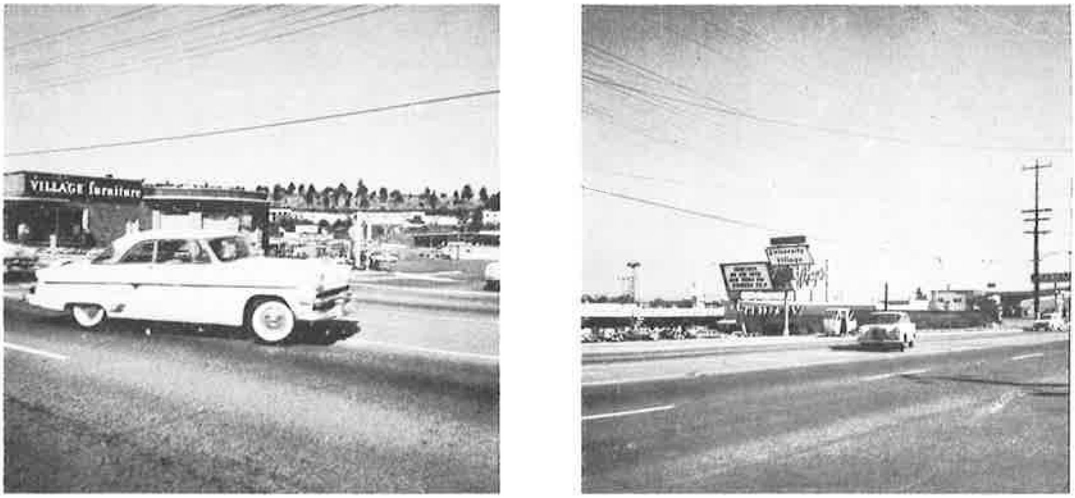


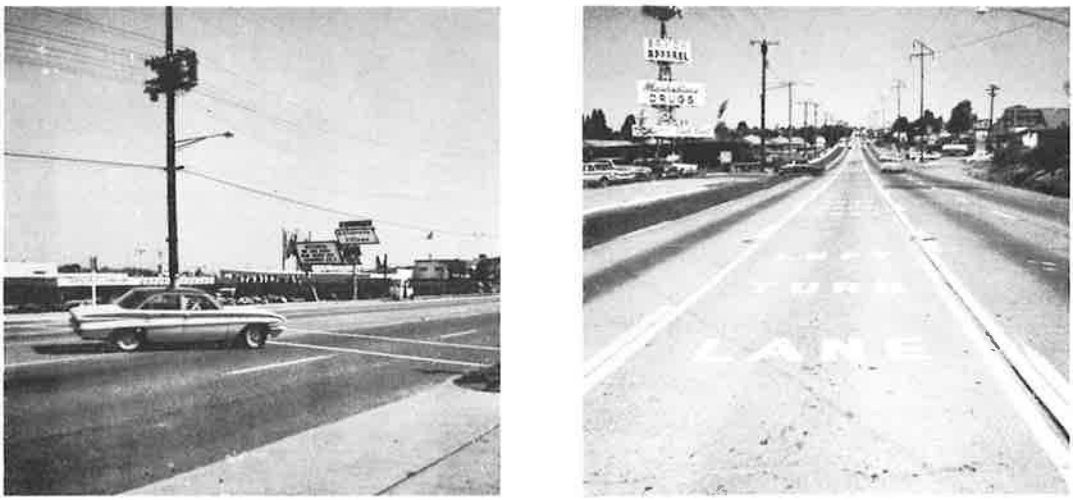
Figure 35. Weekday 2WLTL usage on 25th Ave. N. E., 1962.

driving skills. Two elements are involved in the proper use of the 2WLTL: (a) the motorist must be able to easily recognize the 2WLTL, and (b) he must make use of it.

Confusion over the 2WLTL is obviously greatest among out-of-state drivers. This is reasonable to expect because the 2WLTL is not in common use throughout the nation. Many local drivers from outside the city also do not understand the 2WLTL, and even some of the Seattle drivers fall into this category. Drivers who do not understand the 2WLTL will invariably slow to a stop or near-stop in the inside through lane before executing a left turn to a generator (Fig. 36A). One out-of-state driver did this three consecutive times. In a study of the distance traveled in the 2WLTL before making a left turn to a generator, 17 percent of the out-of-town drivers (most were also out-of-state) made no use whatsoever of the 2WLTL and merely cut directly across it from the inside through lane. Only 3 percent of the local drivers made left turns in this manner.



A. Motorists fail to use 2WLTL in turning left to generators and turn directly from the through lane.



B. Motorists turning left from generators cut directly across 2WLTL. Photo on right shows a vehicle crossing 2WLTL and entering the outside through lane.

Figure 36. Motorists fail to make full use of 2WLTL.

Most automobile drivers enter the 2WLTL on a reverse-curve path and entry is completed within 40 to 50 ft. Typical entry maneuvers by automobiles are shown in Figure 37A. A sample distribution of the distance traveled in the 2WLTL by automobiles at the 25th Ave. N. E. installation is shown in Figure 38. A fairly symmetrical distribu-

A

B C

Figure 37. 2WLTL usage by automobiles on 25th Ave. N. E.

tion is evident for local drivers, with an average travel distance of about 200 ft. Some motorists travel up to 600 ft and more in the 2WLTL. Such excessive use of the 2WLTL can prevent other drivers from entering the 2WLTL and is undesirable. Non-local drivers from outside King County have an average travel distance of about 140 ft. The distribution of travel distances is skewed extremely to the right. Such a difference is not surprising since non-local drivers probably do not realize the purpose of the 2WLTL until they are nearer their point of turning, and they are probably more cautious also. This would result in shorter travel distances for this group. Some research into signing for 2WLTL's would be desirable. Perhaps symbolic signing could supplement the conventional signs to inform the unfamiliar driver with regard to proper use of the 2WLTL.

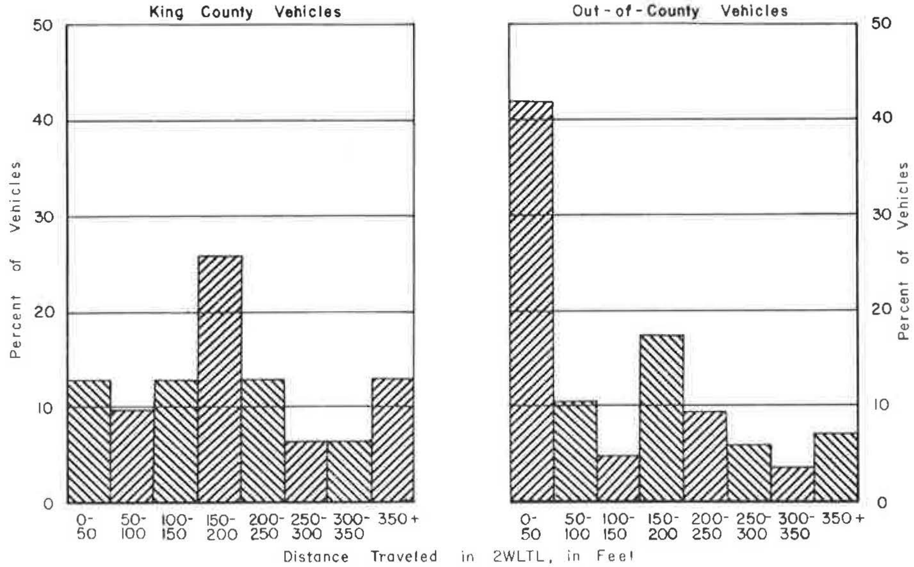


Figure 38. Distance traveled by automobiles in 2WLTL prior to making a left turn.

TABLE 14

DISTANCE TRAVELED IN 2WLTL BEFORE LEFT TURN

Automobile Registration	Automobiles Sampled	Travel Distance (ft)			
		Average			Median
		Rush Hour	Non-Rush Hour	Rush and Non-Rush Hour	Rush and Non-Rush Hour
King County	62	230	180	200	180
Out-of-county	86	140	130	140	100

Table 14 summarizes the average travel distances for local and out-of-county drivers. Travel distance is longer during rush-hour traffic than during the non-rush-hour period. One might reasonably expect that during non-rush-hour periods, a motorist probably does a larger portion of his deceleration in the through lane because traffic is light and it does not cause undue delay to other vehicles. When traffic is heavy, most of the deceleration will be in the 2WLTL. Furthermore, when traffic is heavy a driver cannot take the chance that the 2WLTL will not be occupied when he desires to enter it. Statistical analysis, however, showed no significant difference between the rush and non-rush-hour groups. Out-of-county motorists apparently do not travel any further in the 2WLTL during rush-hour traffic than during non-rush periods.

On 25th Ave. N. E. during rush hours, 15-min volumes were approximately 350 vehicles, whereas non-rush hour volumes averaged 225 vehicles per 15-min period.

Braking before entering the 2WLTL is not too common for drivers who enter the 2WLTL a reasonable distance ahead of their left turn. Braking before entry occurs more frequently among drivers who make little use of the 2WLTL. Even when drivers do not brake when entering the 2WLTL, many begin to decelerate in the through lane

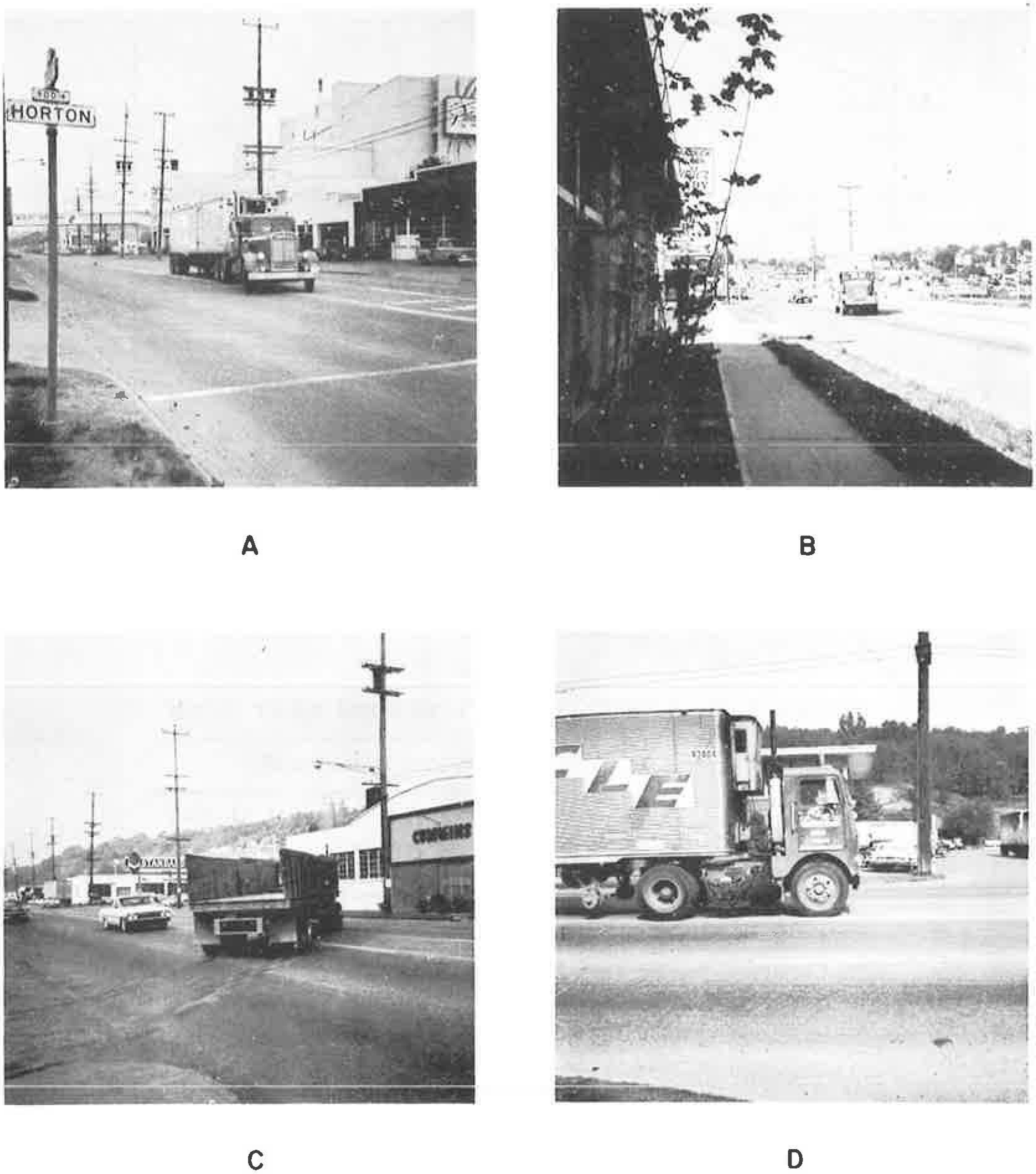


Figure 39. 2WLTL usage by trucks.

(perhaps from 30 to 25 or 20 mph) just before crossing over into the 2WLTL. This is probably because driving over the rounded steel traffic buttons gives an unpleasant jolt and motorists slow down in order to enter the 2WLTL and avoid the buttons. Smaller buttons with less height and closer spacing would probably be better, although this arrangement might be more expensive.

Figure 37B shows several automobiles waiting in line for the opposing traffic to clear before making their left turn. The 2WLTL offers an advantage over the unidirectional left turn with regard to limitations of storage and stopping in the through lane because the left-turn lane is full. There is fairly even placement of the vehicles in the 2WLTL. Figure 37C, however, shows a left-turning vehicle crowding the 2WLTL lane

TABLE 15

TURN SIGNAL INDICATIONS WHEN USING THE 2WLTL

Movement	Type	Signaling (%)			Not Signaling (%)
		Entering & Exiting 2WLTL	Entering 2WLTL Only	Exiting 2WLTL Only	
To generator	Autos	69.7	-	5.4	21.0
	Trucks	60.8	-	19.6	19.6
From generator	Autos	1.9	30.2	-	67.0
	Trucks	4.5	35.8	-	59.7

line. Such placement is more likely to slow up through traffic as it approaches the vehicle and in general does not appear to be a desirable practice.

Automobiles turning left from generators and into the through lanes usually make little use of the 2WLTL as an acceleration-merging lane. Most drivers wait for a gap in traffic, cross the 2WLTL at nearly a right angle, and turn into either the inside or outside through lane (Fig. 36B).

General observations of the use of the 2WLTL by trucks on Airport Way show that these drivers tend to use the 2WLTL in a fairly satisfactory manner. Figures 39A and B show trucks gradually easing into the through lane as they use the 2WLTL to accelerate to through traffic speed. Truckers make use of the 2WLTL for left turns from the generators to the through lanes (Fig. 39C). The large trucks occupying the 2WLTL in A and D demonstrate the desirability for providing a lane width equal to and perhaps greater than that of the through lane, which should be at least 10 ft wide.

Few drivers use the 2WLTL as a passing lane. The high buttons that Seattle uses on 2WLTL's probably helps to discourage this.

Turn-Signal Indications

Signaling either by hand or turn-signal indicator when changing lanes on a multilane street or highway helps to prevent accidents. This phase of the operation's study was aimed at determining the extent of signal use when vehicles use the 2WLTL for turns to and from generators. For 2WLTL movements from the through lanes and to generators there are four possibilities with respect to signaling: (a) signaling both while entering and exiting the 2WLTL—both left-turn signals; (b) signaling on entry only; (c) signaling on exit only—as the driver is about to begin his left turn; and (d) no signals. For 2WLTL movements from generators to the through lanes, there are also four possibilities: (a) signaling both when leaving the generator (left-turn signal) and when leaving the 2WLTL and entering the through lane (the latter would call for a right-turn signal, assuming that the motorist uses the 2WLTL as an acceleration lane); (b) signaling when leaving the generator only; (c) signaling when entering the through lane only; and (d) no signals. Table 15 is a sampling of automobiles and trucks at 25th Ave. N. E. and Airport Way, respectively. The samples were broken down into rush-hour and non-rush-hour vehicles, and for each vehicle type, the two groups gave virtually the same results.

There does not appear to be much difference between automobiles and trucks in most categories (Table 15). Although the automobile data and truck data were not collected from the same 2WLTL installation, street widths and volumes are fairly similar for these installations. Approximately 80 percent of the vehicles signal at least once when turning into generators, but only about 40 percent signal at least once when turning out of generators. This is not surprising because most drivers realize that a left turn from the main street is more hazardous than one from a generator. In the latter case, drivers usually wait until there is a gap in traffic and probably feel that a signal is not really necessary.

ACKNOWLEDGMENTS

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Approach-End Treatment of Channelization—Signing And Delineation

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The general objectives of the research project were to evaluate the effects of design, signing, delineation, and illumination of channelization on the factors of safety, efficiency of operation, and capacity. The specific phases of research covered in this report dealt with the signing and delineation of channelization, and with the effect of channelization and approach-end treatment on certain characteristics of driver behavior.

• IN 1960, the research project, "Channelization" was initiated by the Texas Transportation Institute in cooperation with the Texas Highway Department. Its general objectives involved investigating the effects of design, signing, delineation, and illumination of channelization on the factors of safety, efficiency of operation, and capacity. The specific phases of the research covered in this report dealt with the signing and delineation of channelization, and the effect of channelization and approach-end treatment on certain characteristics of driver behavior. Because of the discrete nature of the studies, each of the subjects is presented separately in the report.

To avoid hazardous situations, careful consideration must be given to the approach-end treatment of channelization in regard to design, signing, and delineation. Signing used to denote the beginning of the island, and to locate it with respect to the roadway cross-section should have excellent visibility characteristics to provide adequate advance warning to the driver. In addition to signing of the approach-end, the island curb should be delineated from the remainder of the roadway to establish a proper perspective of the change in geometric conditions. The delineation should provide continuity over a considerable distance so that the driver will be aware of the overall configuration of the introduced channelization. Finally, the channelizing island and approach-end treatment must be designed geometrically to provide a natural maneuver for traffic to flow around the island.

In the first phase of this research, several materials were tested under controlled conditions to determine their relative effectiveness in delineating island curbs. The superior material, as indicated by the controlled tests, was then installed under actual traffic conditions to provide an evaluation of its practical performance characteristics.

In the second phase, several KEEP RIGHT signs used on channelization were tested to determine their relative visibility and legibility characteristics. In the third phase, studies were made at three stages in the development of channelization and approach-end treatment to determine the effect on driver behavior. In these studies a GSR recorder was used to measure driver tension responses, and traffic speeds were measured through several sections of the channelized area.

DELINEATION

Several currently used delineation materials were tested to determine their comparative effectiveness. Then the most effective of the materials was used in studies of performance under actual traffic conditions.

Paper sponsored by Committee on Operational Effects of Geometrics.

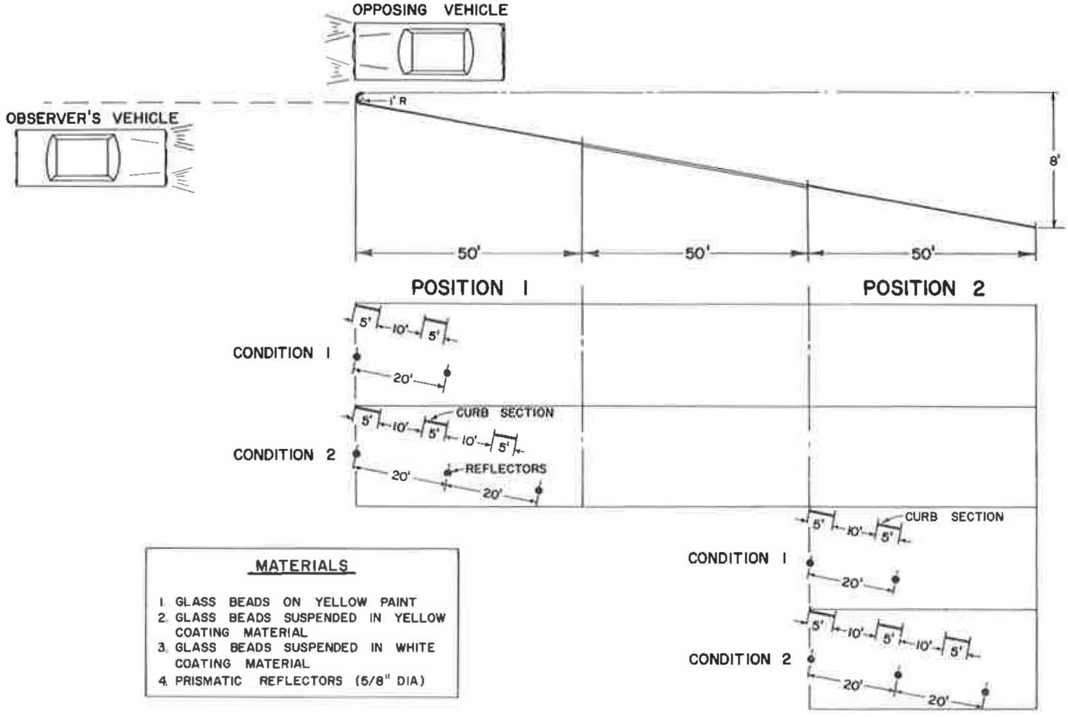

Figure 1. Delineation test site.

Comparison of Delineation Materials

In this phase of the research, studies were conducted to evaluate comparatively the effectiveness of several materials currently used in delineating island curbs. The materials tested were (1) yellow paint reflectorized with glass beads, (2 and 3) highly reflective coating material with glass beads in suspension (yellow and white), and (4) prismatic-type reflectors (5/8 in. in diameter) mounted on top of the island curb.

Description of Study

To facilitate a comparison of the materials, simulated conditions of channelization were devised and tested on runways at the Texas A & M College Research and Development Annex, which was at one time the Bryan Air Force Base. Through such controlled conditions it was possible to eliminate a number of variables such as grade, alignment, outside light sources, and variable opposing headlights that would normally be encountered in tests of the materials at actual installations of channelization.

To simulate a channelizing island, 5-ft long curb sections were constructed of wood and shaped to resemble a barrier-type island curb. The curb sections were coated with the various test materials. The prismatic reflectors were mounted in wooden blocks that could easily be aligned with the path of the test vehicle. To form the approach-end of the island, an island nose was shaped from sheet metal and reflectorized, and either the curb sections or the reflectors were placed along a line from the island nose tapered for a lateral transition of 8 ft in 150 ft of length. The details of the island layout and the test conditions are shown in Figure 1.

The materials were tested at two positions along the taper to determine any effects of the relative position of the materials with respect to a vehicle with opposing head-

TABLE 1

RESULTS OF CURB DELINEATION STUDY

Position	Driver No.	Replication No.	Visibility Distance (ft) Material 1, Condition 1	Material 1, Condition 2	Material 2, Condition 1	Material 2, Condition 2	Material 3, Condition 1	Material 3, Condition 2	Material 4, Condition 1	Material 4, Condition 2
Position 1	1	1	200	160	120	140	180	180	760	760
		2	200	220	140	180	180	160	840	920
	2	1	220	200	160	180	160	220	680	680
		2	200	220	140	240	140	180	580	740
	3	1	140	200	120	120	180	160	620	580
		2	160	200	180	140	180	180	660	820
	4	1	200	200	140	180	200	240	640	680
		2	160	240	160	140	200	200	600	700
Avg.			185	205	145	165	178	190	672	735
			195		155		184		704	
Position 2	1	1	200	140	140	120	140	160	1,040	1,080
		2	140	160	160	140	140	140	820	880
	2	1	120	180	120	140	140	140	800	840
		2	140	160	100	120	100	100	600	660
	3	1	160	120	100	80	140	140	560	460
		2	180	160	100	100	160	140	720	660
	4	1	220	220	120	180	140	220	980	1,060
		2	180	200	180	140	160	160	1,000	1,020
Avg.			167	167	128	128	140	150	816	834
			167		128		145		825	

lights at the island nose. Position 1 consisted of placing the curb sections and the reflectors in the 50-ft section of the taper immediately following the island nose. For position 2, the curb sections and reflectors were placed in the third 50-ft section of the taper.

To test the effect of length or continuity of the delineation provided by the materials, two test conditions were established. Condition 1 consisted of two curb sections placed 10 ft apart, or two reflectors placed 20 ft apart. For condition 2, three curb sections or three reflectors were used at the same spacing (Fig. 1).

The visibility tests were conducted with an opposing vehicle and the observers' vehicle operating on low-beam headlights. The opposing vehicle was parked at the nose of the island to simulate the most critical condition of two vehicles meeting under actual conditions. The exact critical position of the opposing vehicle was verified by preliminary testing.

In the tests, four observers drove a predetermined loop on runways that included the simulated channelization. Prior to beginning the test, each observer was instructed to indicate the number of curb sections or reflectors he could see as he came into the range of visibility. The distance from the nose of the island at which the observer could distinguish the correct number of curb sections or reflectors was determined (to the nearest 20 ft) as the visibility distance. To avoid any anticipation on the part of the observer, the materials, positions, and conditions were completely randomized.

The experiment was designed to test the four materials under two conditions in each of two positions, making possible a total of 16 combinations. Also, two replications of the experiment were required of each observer to increase the reliability of the results.

Findings

The results of the study (Fig. 2) indicate that the prismatic reflectors were visible at distances three to four times those of the other materials. These results show further that there was no appreciable difference in the visibility distances of any of the coating-type materials. Material 1, beads-on-paint, was visible at a greater distance than the other two coating materials. However, the visibility distances of all three materials were below what could be considered acceptable for good delineation. Table 1 lists the results in detail to provide a more exacting comparison.

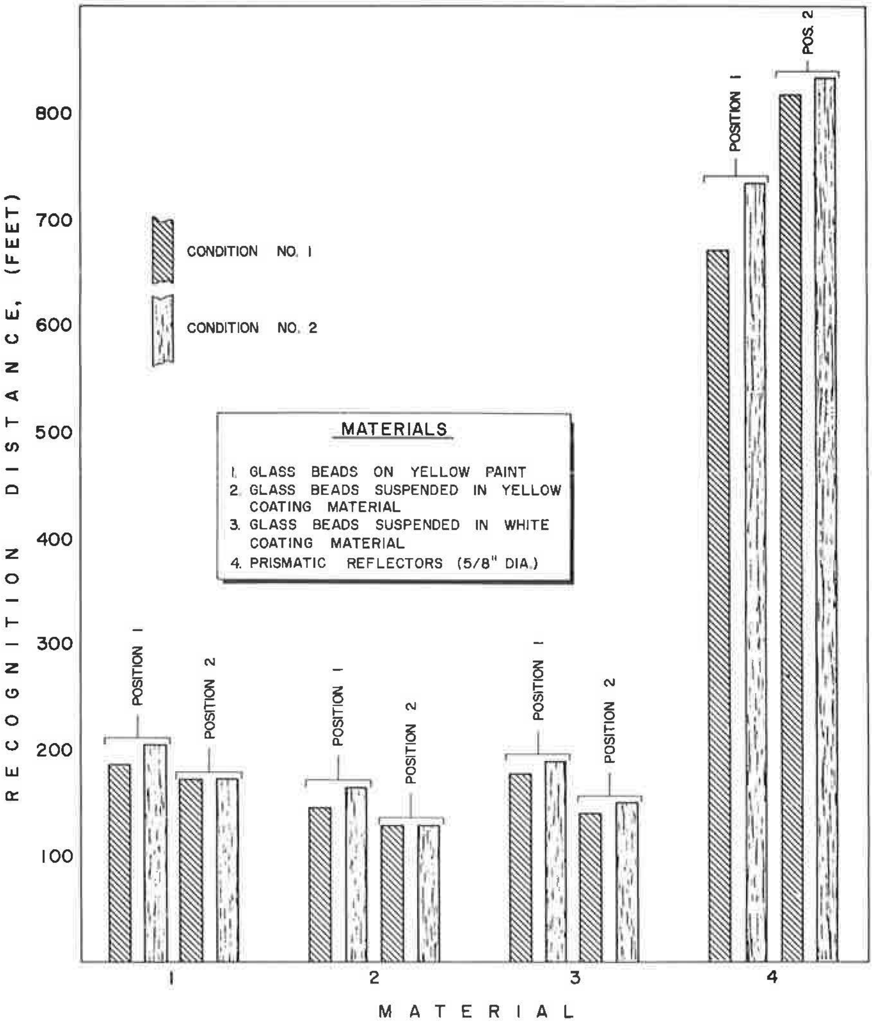

Figure 2. Visibility distance of curb delineation material.

The superiority of the reflectors was primarily attributable to two characteristics:

1. The prismatic reflective surfaces in the reflector provide greater reflection efficiency, and
2. The reflectors were mounted perpendicular to the stream of traffic, whereas, the coating-type materials were placed virtually parallel to the traffic stream.

Preliminary observations indicated that the coating-type materials provided good visibility when the test curb sections were placed perpendicular to the traffic stream. However, the visibility of the curb sections in the perpendicular position was not as great as for the prismatic reflectors. This is substantiated by the results of visibility tests on signs constructed of the same or similar materials discussed later.

Visibility vs Position.— A comparison of the visibility distances of the materials according to their position relative to the island nose and hence relative to the opposing vehicle (positions 1 and 2, Fig. 1) showed that the coating-type materials were less effective in position 2 than in position 1 (see Fig. 2). On the other hand, the visibility distance of the reflectors was increased approximately 100 ft by moving them to posi-

TABLE 2

COMPARISON OF VISIBILITY DISTANCES OF MATERIALS FOR NORMAL WEATHER CONDITIONS VS INCLEMENT WEATHER CONDITIONS

Material	Visibility Distance			
	Position 1		Position 2	
	Visibility Range, (ft)	Avg. Visibility Distance, (ft)	Visibility Range, (ft)	Avg. Visibility Distance, (ft)
Material 1, beads-on-paint	100-160[1]	130[1]	0-120[1]	60[1]
	140-240	195	120-220	167
Material 2, yellow reflective coating	60-80[1]	70[1]	40-80[1]	60[1]
	120-240	155	80-180	128
Material 3, white reflective coating	60-80[1]	70[1]	60-80[1]	70[1]
	140-240	184	100-220	145
Material 4, ⅝-in. prismatic reflectors	440-500[1]	470[1]	420-760[1]	590[1]
	580-920	704	460-1080	825

[1]Slow steady drizzle with wipers on.

tion 2, 100 ft behind the island nose. This increase in performance was attributed to the fact that moving the reflectors 100 ft along the taper also moved them 5 ft laterally and reduced the effect of the "halations" of the opposing vehicle's lights. The other three materials showed a slight decrease because their reflective power was not great enough to compensate for the increased distance from the light source. The visibility distances were measured from the island nose rather than from the actual position of the material.

Visibility vs Condition.—Increasing the number of curb units or reflectors from two to three such as in conditions 1 and 2, increased the visibility only slightly in position 1 and practically none in position 2. This increased visibility indicated a dissipation of the halation's effect of the opposing headlights when the materials were laterally removed. This also is an indication that continuous delineation offers greater advantages than a concentration of materials at the island nose.

These differences in visibility distances according to position and condition were not statistically significant. However, the differences were considered worthy of mention because of the consistency of the results.

It is logical that the delineation, when tested under controlled conditions, bore greater significance when all outside light sources were eliminated except for the opposing vehicle. This probably resulted in greater recognition distances than could be expected under actual conditions. However, the study was aimed at evaluating comparative visibility more than actual distances at which the materials were visible.

Visibility vs Inclement Weather.—On one particular occasion, a slow drizzle interrupted the normal testing of materials. Rather than cancel the night's work, limited tests were conducted to evaluate the visibility of the materials during inclement weather. The test data were obtained using two drivers in one replication of the study. The results given in Table 2 in comparison with normal weather tests indicate a general reduction in visibility of about 50 percent due to inclement weather conditions. The reflectors were not affected as much as the coating-type materials. It is significant to note that the reflectors provided good visibility even in inclement weather.

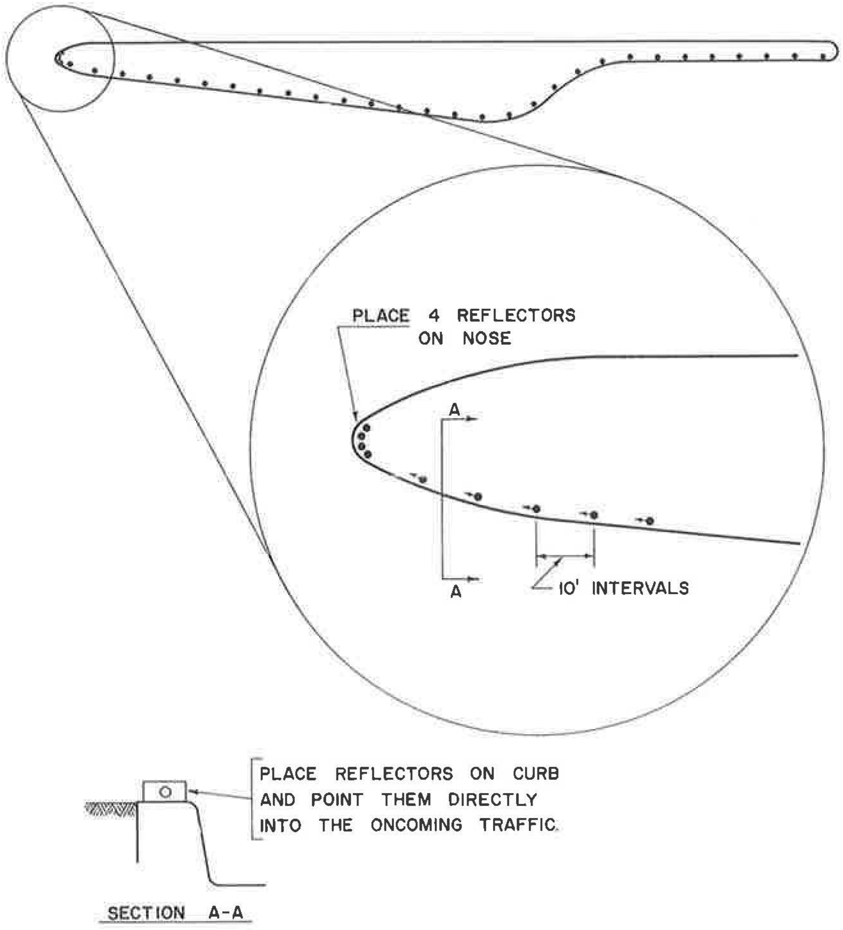

Figure 3. Installation layout for performance studies.

Performance Studies

The results of the tests of delineation materials definitely showed that the prismatic reflectors offered the greatest effectiveness under controlled conditions of testing. To evaluate the efficiency of the reflectors under actual traffic conditions, they were installed on several divisional islands in the Houston, Bryan, and Waco districts of the Texas Highway Department. In Houston and Bryan, the reflectors were installed on divisional islands on arterials carrying high traffic volumes through highly developed areas. The locations were illuminated with mercury vapor-type luminaires.

In the Waco district and at another location in the Bryan district, the reflectors were installed on islands in rural areas where traffic volumes were low and outside light sources were negligible. The reflectors were installed in wooden blocks with the face of the reflector mounted flush with the face of the block. The wooden blocks were then mounted on top of the curb at 10-ft intervals (Fig. 3). The wooden blocks were not considered permanent mounting facilities, but merely an economical means of holding the reflectors in place for observation under actual traffic conditions.

No tests were conducted to evaluate the actual visibility distances of the reflectors under normal service because the variables that could influence their visibility were too great in number for the results of such a study to be of any great significance. However, observations indicated that the reflectors performed satisfactorily when first installed, even in the lighted areas.

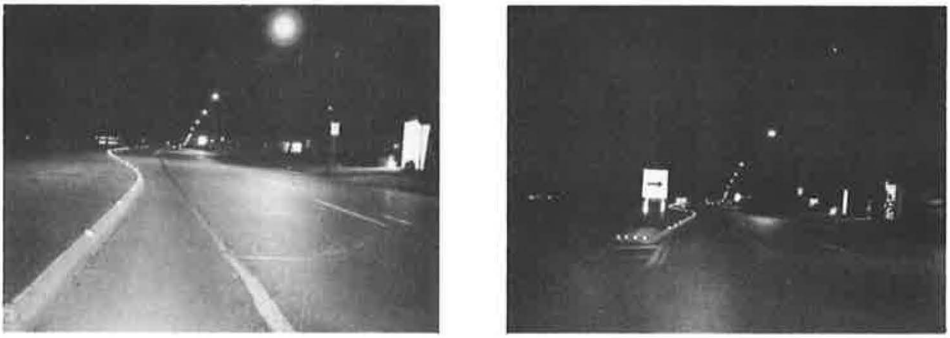

Figure 4. Delineators at night, Bryan urban installation.

The Bryan urban installation is shown in Figure 4 and the real advantage of the prismatic reflectors is illustrated. Due to their great range of visibility, the entire divisional island including the added left-turn lane is clearly outlined before the driver. As an indication of the range of visibility, the island was approximately 500 ft in length with an opening at 310 ft. This view is comparable to the driver's view of the island when approaching with high-beam headlights. For low-beam conditions, approximately the same view is seen with slightly less intensity.

The reflectors installed in the rural locations have given satisfactory service with little or no maintenance required. The installation in the Waco district has drawn numerous favorable comments from highway patrolmen and officials of a nearby military base. Apparently, the delineators have improved the visibility of introduced divisional island channelization at a high-speed rural intersection.

The performance studies in the urban areas have pointed up maintenance problems that must be resolved through further experimentation. During inclement weather, the visibility of the reflectors was reduced by road film coating the face of the reflectors. The Houston test installation was most seriously affected by weather conditions. However, it was anticipated that Houston would be the most critical test area because of a great amount of rainfall combined with the existing soil type and poor drainage due to flat topography.

The reflectors installed in the Bryan area provided acceptable service for a period of three months (Sept. to Dec.) when there was not a great amount of rainfall. During that time, it was estimated that their reflectivity was reduced approximately 30 percent by road film coating the face of the reflector. Shortly afterward, they were subjected to an extended period of slow drizzle and rain in which their reflectivity was reduced about 75 percent. However, it was observed that heavy rains removed some of the road film and thus restored an appreciable amount of their reflectivity. The fact remains that the reflectors, mounted as previously described, are in some cases subject to road film and are not effective during inclement weather when most needed. This pointed out a definite need for the development of a mounting device for the reflectors which will serve as a shield from the splash or road film.

The amount of road film and the rate of its deposition on the face of the reflectors are considered to result from the amount of dirt and foreign matter on the roadway, the proximity of the traffic stream and the volume of traffic in the lane adjacent to the reflectors. From the performance studies, it appears that the proximity of the traffic stream may have the greatest effect. However, all of these factors will be considered in further research.

SIGN VISIBILITY

It is common practice to utilize the KEEP RIGHT sign in directing traffic around channelizing islands. Most frequently the sign is used in conjunction with painted and reflectorized curbs to delineate and define the island. However, signs are quite fre-

SIGN NUMBER 1

SIGN NUMBER 2

SIGN NUMBER 3

SIGN NUMBER 4

SIGN NUMBER 5

SIGN NUMBER 6 & 7

SIGN NUMBER 8

Figure 5. Test signs.

quently used without additional delineation, especially in rural areas where channelizing islands normally are not curbed. Therefore, there is considerable dependency on the proper function of the KEEP RIGHT sign, particularly where it is used alone.

First, due consideration should be given to the true function of the sign. Because it is of generally standard form and so widely used, it probably can be considered more as a symbol than a printed message. For this reason, its recognition or knowledgeable visibility is more important than its actual legibility.

TABLE 3

SIGNS USED IN VISIBILITY AND LEGIBILITY TESTS

Sign No.	Type of Sign	Sign Size (in.)	Letter size (in.)
1	Beads-on-paint; black letters on white background (Texas Highway Department Standard)	24 by 30	5
2	Reflective sheeting; black letters on white background	24 by 30	5
3	White letters and arrow inset with prismatic reflectors on black background	24 by 30	4
4	Internally illuminated; black letters on white opaque background (no arrow)	24 by 36	7
5	Same as No. 1 except black and white hash mark panel mounted below sign	24 by 30	5
	Panel	24 by 36	-
6	Same as No. 1 except externally illuminated	24 by 30	5
7	Same as No. 2 except externally illuminated	24 by 30	5
8	White reflective sheeting letters and arrow on black background	24 by 30	5

The KEEP RIGHT sign is of generally standard form (Fig. 5). However, there are several different innovations, depending primarily on the different types of materials and construction techniques.

Description of Study

Studies were conducted to compare the visibility and legibility characteristics of several types of signs and sign arrangements currently being used. The signs selected for study are shown in Figure 5 and described in Table 3. Most of these signs were selected because of their particular appeal in certain areas. The standard Texas Highway Department sign (No. 1) is used extensively throughout the State; however, some districts have recently gone to other types of signs or modifications of the standard type. In some districts, a hash mark panel has been placed immediately below the KEEP RIGHT sign. Also, some districts have installed external illumination on the standard type signs.

Sign No. 3, on which the message is composed of letters and the arrow formed of prismatic reflectors, has been used favorably on high-type facilities. Also it has seen some application as a KEEP RIGHT sign. Sign No. 8 was selected to provide a materials comparison with No. 3.

Mounting Height.—There are some differences in policy regarding the most effective mounting height for KEEP RIGHT signs. The "Texas Manual on Uniform Traffic Control Devices for Streets and Highways" specifies that such signs on channelizing islands should be mounted with the bottom edge not more than 7 ft nor less than 3.5 ft from the pavement surface. The "Manual on Uniform Traffic Control Devices for Streets and Highways," published by the Bureau of Public Roads, specifies that mounting height should be at least 7 ft in business and residence districts or in any case when there may be obstructions to view. It is logical that the greater mounting height will provide better visibility over the tops of vehicles ahead. Also, it is possible that mounting the sign at the maximum height will increase its visibility by removing it from the influence of opposing headlights. On the other hand, the higher mounting height may reduce the reflectivity of the sign. Since there is apparently no record of such a comparison, all signs were tested at mounted heights of 3.5 and 7 ft.

Test Site.—Tests were conducted to compare the relative visibility and legibility characteristics of the signs. These tests were conducted on the runways at the A & M College Research and Development Annex to provide greater control over the variables influencing sign visibility, and thus provide a more accurate evaluation. Testing in this remote location served to eliminate a number of variables, particularly the effects of external light sources and variable geometrics and grades.

In designing the study, it was recognized that these idealized conditions would not yield actual visibility and legibility distances that would apply directly to field applications. However, the selected testing procedure and conditions were expected to yield a relative comparison of the visibility and legibility characteristics.

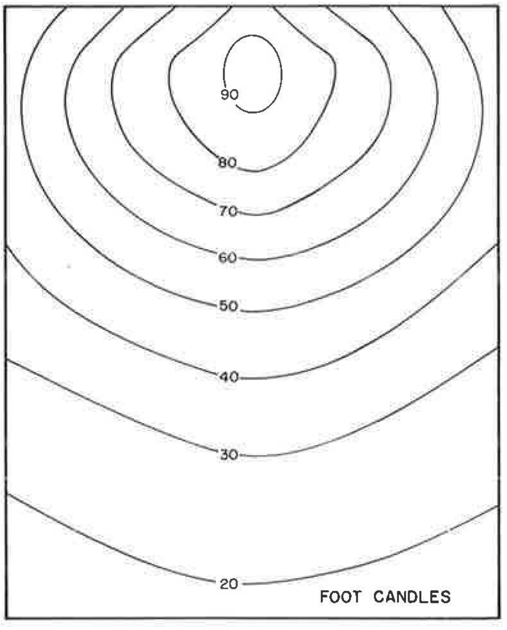

Figure 6. Light intensity pattern for externally illuminated sign No. 6.

Selection of Criteria.—In the selection of criteria for measurement of comparative performance, careful consideration was given to what is believed to be the two primary functional characteristics of the KEEP RIGHT sign. The sign is universally used to mark the approach-end of channelization islands. Such widespread and repetitive application causes the sign to perform as a symbol rather than as a literal message. In other words, the sign has accomplished its purpose when its general shape and the shape of the arrow are visible to the driver. These characteristics are generally visible before it is possible for the driver to read the message. For this reason, the distance at which the driver could recognize the sign in its general form was selected as the primary criterion for comparison. The distance at which all letters of the signs were legible was selected as a secondary measure.

Study Procedure.—To facilitate the study, four observers were selected to drive a vehicle at uniform speed (15 mph) through the test area and indicate the point at which they could recognize the general form of the sign. The distance was also recorded when the driver was able to read the message.

Before beginning the study, the observers were briefed on their duties in the test. Also, trial runs were conducted to familiarize the observers with the signs being used. This was considered necessary to reduce the learning effect inherent in repeated tests involving the human mind. Also, the test runs were considered justifiable because drivers on the roadway frequently encounter the sign, and thus have gained familiarity in its use and purpose.

The test was designed to obtain two observations of each sign by each observer at both mounting heights, comprising a total of 32 observations for each driver. Because of the time consuming nature of the study, the two replications were conducted on separate nights to avoid undue fatigue.

In the test, the signs were drawn randomly within each mounting height to reduce any influences on the data resulting from anticipation by the observer. In other words, the signs were all randomly tested at the 3.5-ft mounting height. The sign mounting brackets were then raised to the 7-ft height and randomly tested again. Testing heights were not randomized because of the difficulty involved in changing the mounting height, particularly in the case of the internally illuminated sign which was permanently attached to the sign support.

An effort was made to simulate the most critical visibility conditions that could normally be expected at any sign installation with exception to weather conditions. To simulate a realistic situation, the observer's vehicle was operated on low-beam lights and an opposing vehicle, also with low-beam lights, was located adjacent to the sign. Preliminary observations ascertained the most critical position of the opposing vehicle to be immediately adjacent to the sign. Apparently the greatest influence of the opposing vehicle is derived from the halation of the glare that surrounds the light. In these same observations, there was no indication that small changes in the angle of the opposing vehicle (0 to 15 degrees) had any appreciable effect on the visibility of the sign.

The external lighting used on signs Nos. 6 and 7 consisted of two 15-w fluorescent tubes mounted in a white reflector. The reflector was mounted 18 in. from the sign

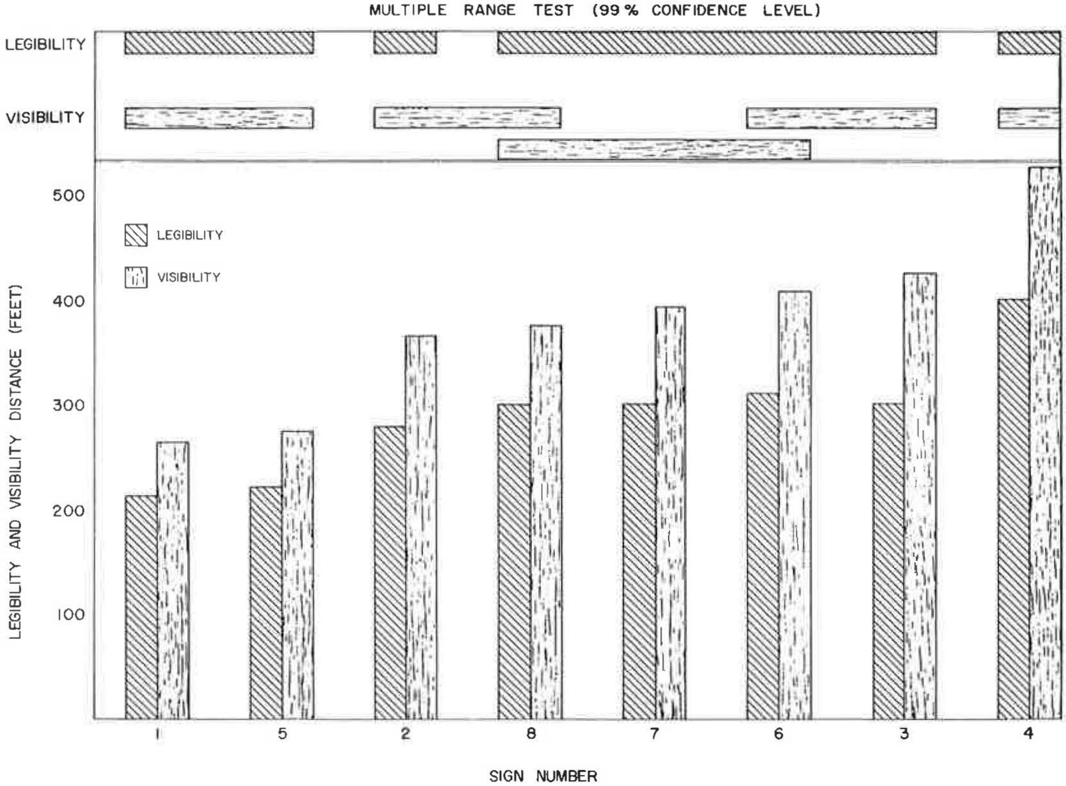

Figure 7. Legibility and visibility distance of signs.

and parallel with the top of the sign. The intensity and distribution of light on the surface of the sign are shown in Figure 6.

Analysis of Data

The data collected in the study of visibility and legibility distances were treated by fixed-effects model of analysis of variance to evaluate any significant differences in the various signs. A multiple range test was applied to the average visibility and legibility distances to rank them according to their order of superiority and establish statistical reliability of any differences in the average values.

Discussion of Results

Visibility Comparisons.—Figure 7 shows the average visibility distance for each sign and the results of the multiple range test in arranging the various signs in groups of significantly different visibility distances. According to this comparison, the internally illuminated sign (No. 4) was superior to all others tested. In the order of relative performance, the second group included the prismatic reflector sign (No. 3) and the Texas Highway Department standard beads-on-paint sign with external illumination (No. 6).

The third group included both externally illuminated signs (Nos. 6 and 7) and the special white reflective sheeting legend on black background (No. 8). The fourth group consisted of the standard reflective sheeting sign (No. 2) and the special sign with reflective sheeting legend. The lowest group in order of performance consisted of the Texas Highway Department standard beads-on-paint type (No. 1) and the same sign with the hash-mark panel mounted below (No. 5).

TABLE 4

ANALYSIS OF VARIANCE SIGN VISIBILITY TEST

Variation Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Drivers	3	4,033.8	1,344.6	151.0[1]
Replications	1	81.3	81.3	9.1[1]
Signs	7	7,729.8	1,104.2	128.0[1]
Drivers/replications	3	161.7	53.9	6.0[1]
Drivers/signs	21	646.4	30.8	3.5[1]
Replications/signs	7	111.4	15.9	1.8
Drivers/replications/signs	21	278.6	13.3	1.5
Residual	64	569.9	8.9	—

[1] 1 percent level.

TABLE 5

ANALYSIS OF VARIANCE SIGN LEGIBILITY TEST

Variation Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Drivers	3	538.2	179.4	138.0[1]
Replications	1	8.5	8.5	6.5[2]
Signs	7	954.1	136.7	105.0[1]
Drivers/replications	3	92.3	30.8	23.7[1]
Drivers/signs	21	160.1	7.6	5.8[1]
Replications/signs	7	16.5	2.4	1.8
Drivers/replications/signs	21	27.0	1.3	1.0
Residual	64	82.5	1.3	-

[1] 1 percent level.
[2] 5 percent level.

The results of this test are not completely clear-cut because there were overlaps in the ranges at signs Nos. 6 and 8. Actually, these signs can be considered in both groups but the groups cannot be combined.

Legibility Comparison.—Average values of the relative legibility distances of the signs are also shown in Figure 7. The results of the range test on the legibility distances were not greatly different from the results of the visibility tests, except that the groups were a little more clearly defined. The internally illuminated sign maintained its superiority. In this comparison the two externally illuminated signs (Nos. 6 and 7), the prismatic reflector sign (No. 3) and the special sign with reflective sheeting legend (No. 8) formed the second group. The standard reflective sheeting sign was alone in the third group. The Texas Highway Department standard (No. 1) and the hash-mark panel variation (No. 5) again comprised the lowest group.

Mounting Heights.—The analysis showed no differences in either the visibility or legibility of the signs at the 3.5- and 7-ft mounting heights under the conditions established in the study. Apparently, any advantages of either height cannot be measured in terms of night visibility or legibility.

Reliability of Results.—As anticipated, the analysis of data for visibility and legibility revealed a great amount of variation in drivers and replications as well as the previously described differences in signs. As indicated by Tables 4 and 5, the great-

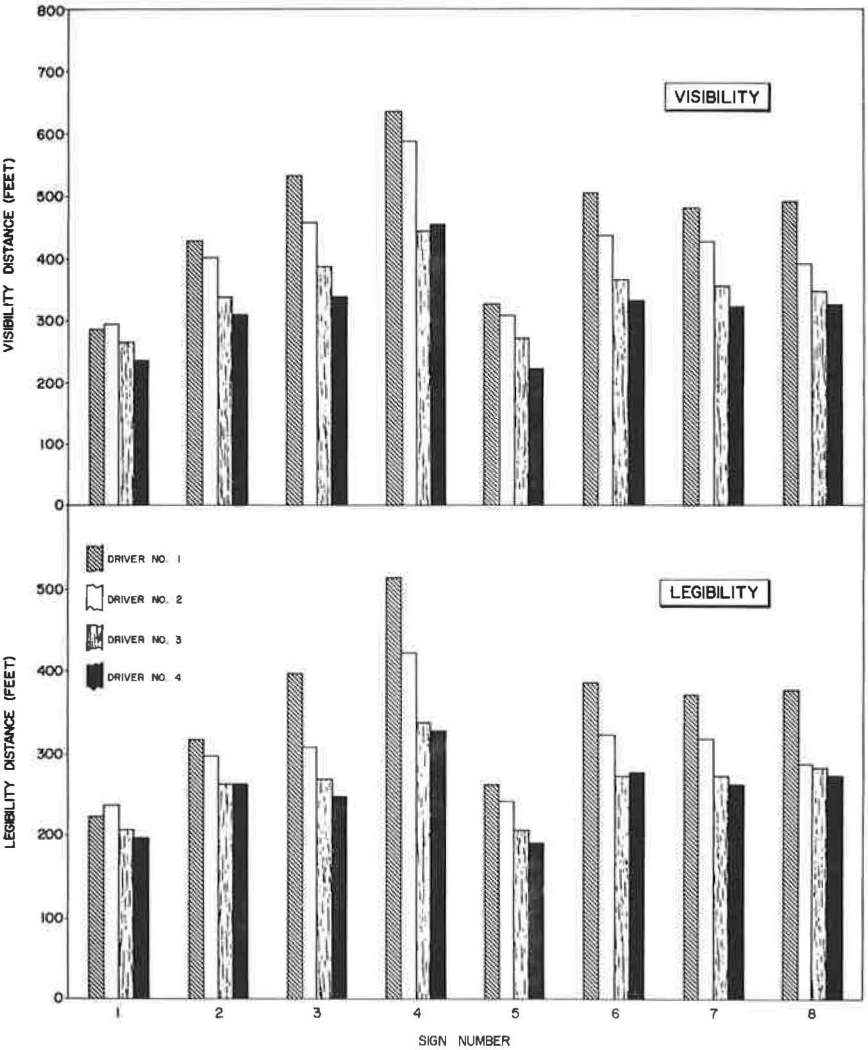

Figure 8. Comparison of legibility and visibility distance of each driver for each sign.

est variation was observed among the drivers. This variation can be explained by the normal differences in visual ability of individuals and should not detract from the results because there was consistency among the relative visibility distances of each of the drivers for each of the signs (Fig. 8). In only two instances (driver No. 1 on sign No. 1 and driver No. 3 on sign No. 6) did the general pattern change.

The analysis of variance indicated significant differences in legibility and visibility distances for each of the two replications. A comparison of the mean distances for each of the replications indicated a decrease between replications 1 and 2 (Table 6). The real causes of these differences are not readily evident. Aside from possible variations due to changes in climatic conditions and in the physical and mental conditions of the drivers, it is theorized that the drivers were more accustomed to the test conditions during the second replication, and therefore, exerted a lesser amount of effort in making the observations. At any rate, the differences in replications are quite small when viewed in light of differences in drivers and signs (Tables 4 and 5).

Because the analysis of variance is based on the assumption that the data are normally distributed, tests were conducted to verify normality. These test results were satisfactory.

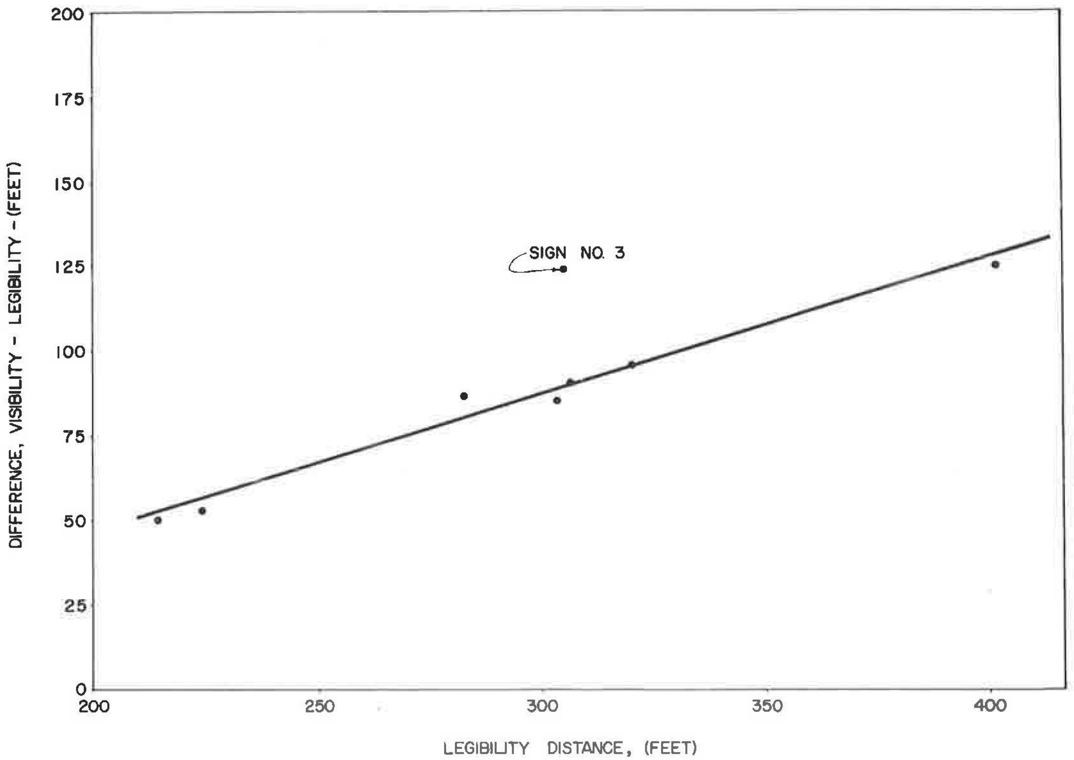

Figure 9. Relationship between visibility and legibility distances of signs.

Evaluation of Results.—The internally illuminated sign provided greater visibility and legibility distances than any other sign tested. However, this indication of superiority must be considered in light of certain circumstances or conditions. The only internally illuminated sign available for testing purposes was a 24- by 36-in. sign with a legend composed of 7-in. letters, which naturally afforded a greater legibility distance than the signs with 5-in. letters.

The second group, which included the prismatic reflector sign, the special reflective sheeting sign, and the externally illuminated word-signs provided good legibility and visibility characteristics. Of this group, the prismatic reflector sign is considered worthy of individual consideration on a practical level because of its relatively high performance characteristics and comparatively low cost of installation. High performance takes on even greater importance when it is recalled that the sign legend is composed of 4-in. letters. The outstanding visibility characteristic of the sign is further demonstrated in Figure 9 which shows a linear visibility-legibility relationship for all other signs tested. However, the visibility of the prismatic reflector sign is proportionately greater than its legibility. This characteristic is attributable to the good visibility of the large arrow displayed on the sign.

The visibility and legibility distances are apparently of great value in evaluating performance characteristics of signs. However, there are a number of other factors to be considered in making a practical selection of a type of sign for marking channelization. The first and primary consideration should be continuity of service. All of the illuminated signs, especially the internally illuminated sign, depend on electrical power and consequently are subject to power failures and bulb or tube malfunctions. As an illustration of this effect, preliminary observations of the signs showed that the visibility distance of the internally illuminated sign was less than 100 ft when power was discontinued. This would indicate no serviceability in the event of power failure.

TABLE 6

SIGN VISIBILITY TESTS: MEAN VISIBILITY DISTANCES

Driver	Sign Number								Avg.
	1	2	3	4	5	6	7	8	
1	280	425	530	635	325	505	480	490	459
2	290	400	455	585	305	435	425	390	411
3	260	345	385	440	270	365	355	345	346
4	230	305	335	450	220	330	320	325	314
Avg.	265	369	426	528	280	409	395	388	382
1[1]	265	380	430	558	288	408	398	398	
2[1]	265	358	422	498	272	410	392	378	

[1]Replication.

A second consideration in the selection of a sign is its contrast with the physical characteristics of the area. In urban or developed areas, there are numerous illuminated advertisements and street lights which reduce the target value of any sign. The internally illuminated sign could be greatly affected because it is quite similar to these foreign light sources. Consideration should be given to the conditions surrounding the site, and to the resulting requirements for visibility and legibility. A final consideration, but by no means least, is the comparative cost of installation, replacement, operation and maintenance of signs.

EFFECT OF CHANNELIZATION ON DRIVER BEHAVIOR

Description of Study

The primary reason for introducing channelization into a roadway is to segregate traffic into more orderly movement. If this is accomplished, the capacity and safety of the facility are increased. On the other hand, the introduction of channelization almost invariably places a physical barrier in the path of the traffic stream. Therefore, considerable dependence is placed on signing and delineation to alert the driver to the physical barrier and guide him comfortably and safely around the island.

Studies were conducted to determine the effect of introducing channelization with normal signing and delineation on driver behavior—more specifically, his tension or emotional level and speed of operation. Additional studies were conducted to evaluate the effect of special techniques of approach-end treatment on driver behavior.

A highway intersection scheduled for channelization was selected, and studies of traffic operation and driver behavior were conducted after each of three stages of installation. The stages of development were:

1. No Channelization.—The section of roadway to be channelized was 28 ft wide; 8-ft paved shoulders were provided.

2. Divisional Island Channelization.—A divisional island was installed to provide a protected left-turn lane (Fig. 10). The approach-end was tapered 8 ft in 150 ft; the island was 12 ft at the widest point. The approach-end treatment was a standard KEEP RIGHT sign mounted near the nose of the island and barrier-type curbs coated with yellow paint and reflectorized with glass beads.

3. Divisional Island Channelization with Special Approach-End Treatment.—The geometrics of the island remained unchanged. The special approach-end treatment was based on the results of previous research on delineation, and other channelizing techniques.

(a) A delineation line conforming to a 1^0 curve was installed beginning approximately 400 ft before the island nose and continuing to the widest point of the

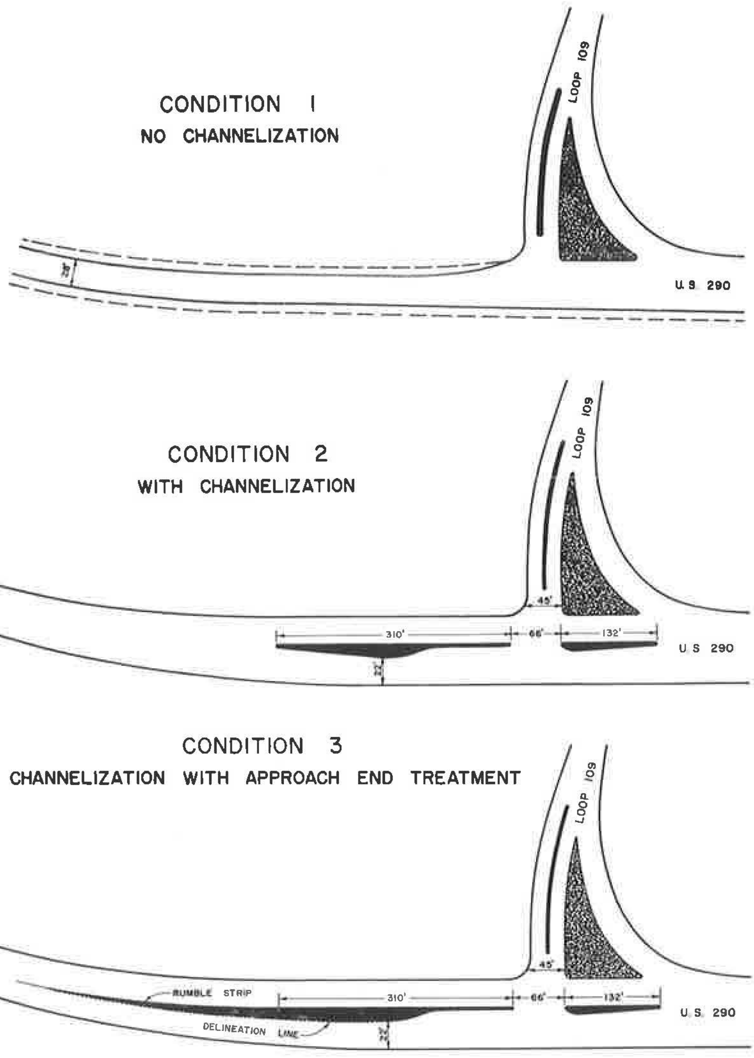

Figure 10. Three stages of channelization.

channelizing island (Fig. 10). This line consisted of 4-in. diameter, button-type lane markers spaced at 3-ft intervals. Two types of markers were used alternately: white reflectorized markers for nighttime visibility and yellow non-reflectorized markers for daytime visibility. The line's purpose was to provide advance warning of the channelization island and outline a smooth transition path around the island.

(b) As a supplement, a rumble strip was installed to provide an audible warning to the driver encroaching on the area between the delineation line and the actual channelizing island. The rumble strip consisted of a surface treatment using ⅝-in. light-colored aggregate.

(c) Prismatic reflectors, ⅞ in. in diameter, were installed on the island curb to delineate the physical barrier. Reflectors were spaced at 25-ft intervals and aimed in the direction of oncoming traffic.

Study Methods.—Two study techniques were used to obtain data on driver behavior and traffic operation. The test car method measured driver tension responses and

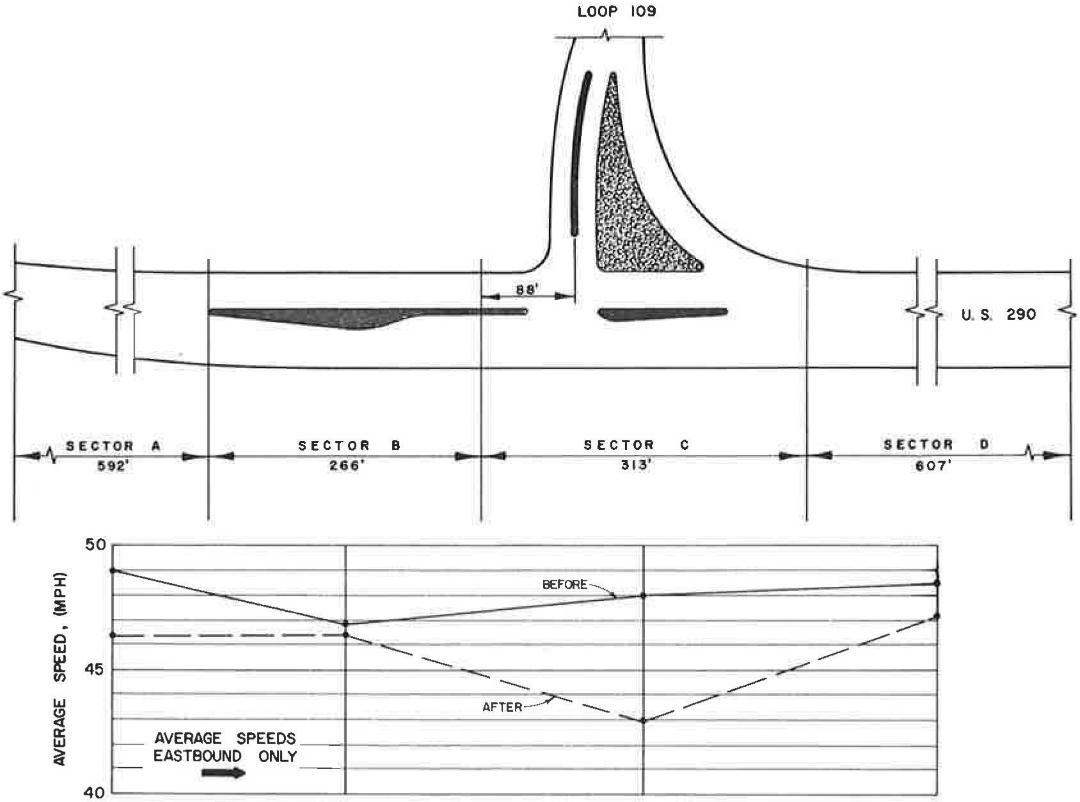

Figure 11. Individual vehicle speed study.

speeds of selected drivers operating a test car in a series of trips through the study area. The individual vehicle-speed study method measured speeds of individual vehicles through several sections of roadway, including the channelized section.

Study Procedures.—Test Car Method—The test car was equipped with a Galvanic Skin Response (GSR) dermograph (1) to measure and record driver tension responses as the drivers traveled through the study area. The test car was also equipped with a recording speedometer to provide a continuous record of vehicle speed.

Four drivers were selected to drive the test car through the study section four times each as a through vehicle and four times as a left-turning vehicle. These drivers, all male college students, were young and experienced. None of the drivers were especially familiar with the study section, and they were not aware of the geometric conditions that existed at the study site before the tests were begun for each condition.

Individual Vehicle Speed Study Method (2)—Studies were conducted to evaluate any differences in the speed characteristics of the vehicles in the normal traffic stream before and after the installation of channelization. The study section was divided into four separate control sections or sectors (Fig. 11). An event recorder actuated by road tubes measured the time required for each vehicle to drive the length of each of the designated sectors. The average speeds for each sector were calculated from the time intervals.

Discussion of Results

GSR Study.—To evaluate differences in driver behavior for each of the three conditions of channelization, the GSR responses occurring in the section extending from the center of the intersection to a point 1,000 ft in advance of the intersection were selected

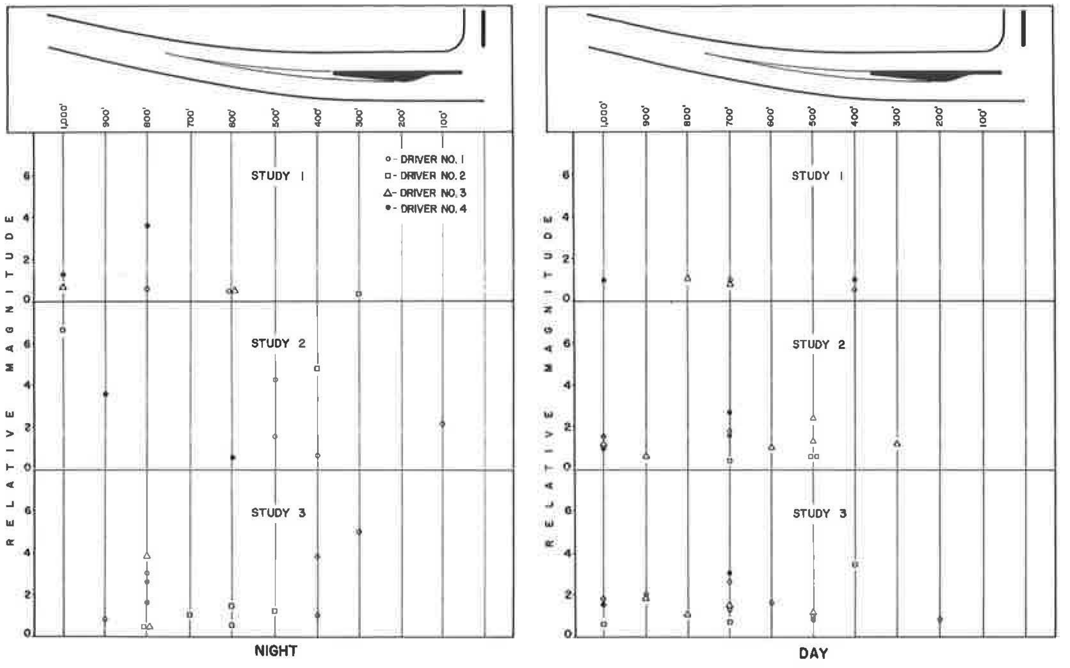

Figure 12. GSR tension responses, through vehicle runs.

for a comparative analysis. The GSR responses of all drivers were examined on the basis of total frequency and total magnitude to determine any differences in driver behavior.

The results of the GSR studies (Fig. 12) indicate a relatively small number of tension responses in all of the studies for both day and night. The number of responses per study ranged from 6 for Study 1 (no channelization-day) to 17 for Study 3 (channelization with special approach-end treatment). These responses were observed during four runs made by four drivers, or a total of 16 runs for each study. Also, two drivers were more responsive than the other two and contributed approximately 65 percent of the responses. In view of the relatively small number of responses and the existent variability in drivers, it was felt that comparisons should not be interpreted as definite conclusions, but only as general indicators of driver behavior.

A greater number of responses were recorded in Study 3 for both day and night runs (Fig. 12). These responses were distributed along the general area of the delineation line but showed a greater concentration at a point 800 ft from the intersection, corresponding to the beginning of the delineation line. These patterns and the increased number of responses indicate that the special approach-end treatment did serve to forewarn the driver of the introduced channelization and the intersection ahead.

Test Car Speed Profiles.—No meaningful comparison could be made of test car speed profiles because of the great variation.

Individual Vehicle Speed Study.—The speeds observed for the before and after conditions of channelization are shown comparatively in Figure 13 for the eastbound direction only. Statistical tests showed significant differences in the mean or average speeds in sectors A and C but not in sectors B and D (Fig. 11). The difference observed in sector A indicated that channelization and the special approach-end treatment caused traffic to reduce speed at a greater distance from the intersection. The speed reduction in sector C indicated that drivers were made more aware of the potential hazard at the intersection and did not return to normal speed until they were clear of the channelized section. Before channelization was installed, the drivers returned to normal speed

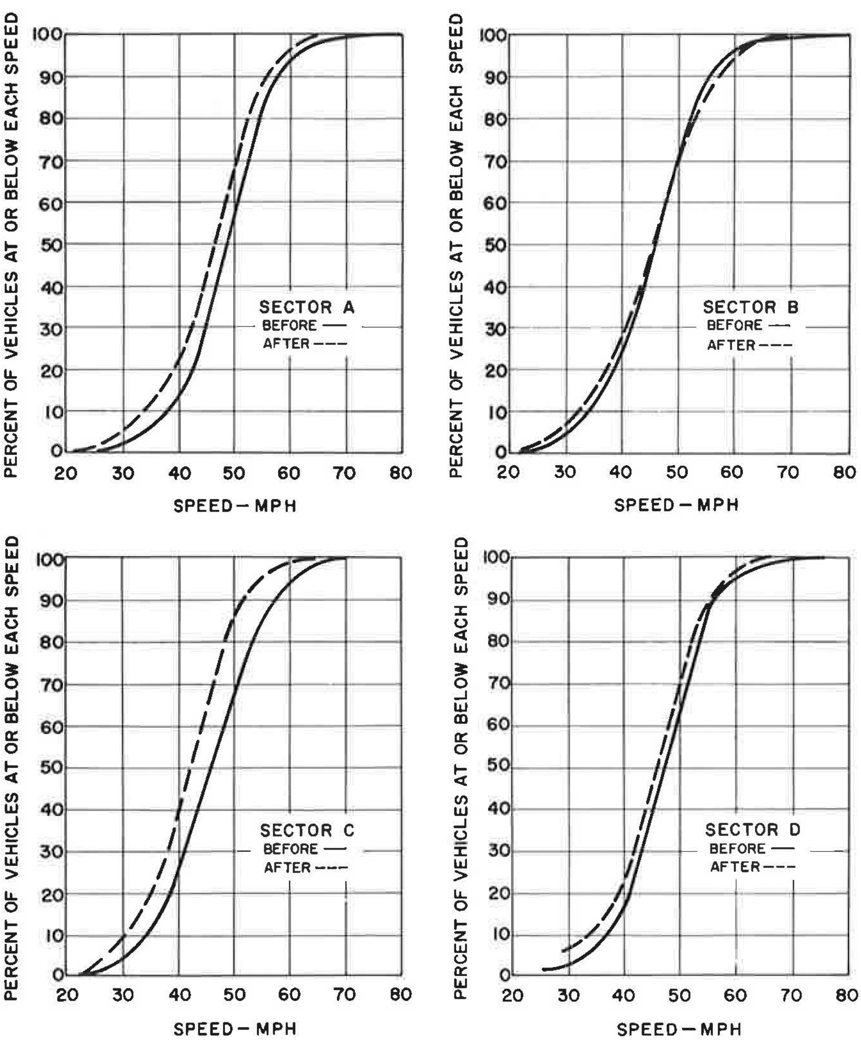

Figure 13. Speed distribution curves for before and after conditions of channelization.

immediately after clearing the intersection. According to these results, channelization has, in effect, extended the intersection area to the limits of channelization and increased its significance.

Evaluation of the Approach-End Treatment

Delineation Line.—The design of the delineation line was intended to provide a natural path around the channelizing island. To establish its effectiveness in providing a smooth transition around the channelizing island, general observations were made of the placement of 382 vehicles classified as (a) vehicles that encroached on the delineation line; (b) vehicles that approached but did not encroach; and (c) vehicles that remained approximately the same distance from the line throughout its length.

The results showed that 28.5 percent of the observed vehicles changed their placement with respect to the delineation line and 8.1 percent of these actually encroached. However, only a few of those encroaching remained on the line any length of time due to the noise produced when the tires struck the buttons. No vehicles were in any danger of striking the island at any time.

CONDITION I - NO CHANNELIZATION

CONDITION 2 - CHANNELIZATION

CONDITION 3 - DELINEATION LINE

CONDITION 3 - RUMBLE STRIP

CONDITION 3
NIGHT VIEW OF
DELINEATION LINE

Figure 14. Views of Elgin Study.

Although the delineation line did accomplish its purpose of guiding traffic around the island, it apparently did not provide a completely natural path as indicated by the high percentage of vehicles changing their placement with respect to the line. It is possible that a smaller degree of curvature, a spiral curve, or a tangent section would have provided a more natural path.

Rumble Strip.—The ⅝-in. aggregate did not produce the desired noise level, especially at lower speeds. Also, the color contrast provided by natural aggregate colors was not satisfactory.

Curb Delineation.—The island curb delineation provided by the prismatic reflectors was considered to be very effective. Figure 14 shows the relative brightness produced by the delineators.

SUMMARY OF FINDINGS

Because the total number of GSR tension responses observed in the driver behavior study was low, the results of that portion of the research were interpreted as general indications rather than definite conclusions. The results of the studies of driver behavior and traffic speeds in a channelized area are summarized as follows:

1. Both conditions (2 and 3) of channelization indicated an influence on driver behavior by an increase in tension responses at night. These tension responses were considered as indications that the drivers were responsive to the warning produced by the channelization.
2. The special approach-end treatment (condition 3) produced greater tension responses than either of the other two conditions, particularly at a point 800 ft in advance of the intersection. This point was coincidental with the beginning of the special approach-end treatment.
3. The installation of channelization with an adequate approach-end treatment caused drivers of the normal traffic stream to reduce speed at a greater distance before the intersection than where the channelization was not present. Also, drivers did not begin to accelerate until they had cleared the channelized area, whereas under unchannelized conditions, they began to accelerate immediately on passing the intersection.

CONCLUSIONS

The following conclusions were drawn from the results of this research:

1. In the tests conducted under controlled conditions, the prismatic reflectors exhibited excellent visibility characteristics and were far superior to curb coating-type materials in delineating channelizing island curbs.
2. The prismatic reflectors performed satisfactorily as curb delineators under actual traffic conditions in rural areas. However, in some urban areas the efficiency of the reflectors was substantially reduced by splash or road film. The reduction in efficiency occurred in the approach-end taper section where the roadway was not well drained and high traffic volumes passed very close to the reflectors.
3. In the tests of KEEP RIGHT signs, the internally illuminated sign provided greater visibility and legibility distances than all other signs tested. However, much of this superiority must be attributed to the fact that the sign legend was composed of 7-in. letters and only 4-in. letters were used on the prismatic reflector sign and 5-in. letters on all others.
4. The prismatic reflector type, externally illuminated, and the reflective sheeting type signs provided good visibility and legibility characteristics. When compared to the internally illuminated sign, they had relative visibilities of 80 percent to 70 percent, respectively.
5. The introduction of channelization with special approach-end treatment caused traffic to reduce speed at a greater distance from the intersection and continue at a reduced speed through the channelized section. A further reduction in speed in the immediate intersection area indicated that the channelization increased the significance or importance of the intersection.

ACKNOWLEDGMENT

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Special thanks are extended to the members of the Advisory Committee for their advice and assistance, and to Ronald D. Eubanks, Research Assistant, for his services in conducting the third phase of this research.

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