Operational Study–Schuylkill Expressway

ROBERT H. PEARSON and MICHAEL G. FERRERI, Traffic Engineers, Simpson and Curtin, Philadelphia, Pennsylvania

In February and March of 1960, a study was made of traffic operations on the Schuylkill Expressway in Philadelphia to determine design deficiencies and the necessary remedies. Studies included mechanical and manual volume counts, lane distribution, vehicle classification, radar speed distribution, travel time, delays to ramp vehicles, gap acceptance and rejection at ramps, a review of accident experience, and a motion picture analysis of peak-hour Expressway conditions. Ramp capacity studies were made at several on-ramps which have little or no acceleration lanes (0 -150 ft) and are controlled by stop signs.

The data were recorded in sufficient detail to yield: (a) frequency and time length of gaps in the Expressway shoulder lane, (b) the time length of each accepted and rejected gap, (c) the time length of gaps accepted by a queue of vehicles, (d) the speed of each shoulder lane vehicle, (e) total delay to each ramp vehicle, and (f) the delay to each ramp vehicle while waiting as the first vehicle in line. Data were recorded in peak hours with ramps under constant pressure. Information was obtained manually using stop watches.

Using this information, a high coefficient of correlation was obtained for a curve of ramp capacity as a function of shoulder lane volume. Several other variables were examined to determine their effect on ramp capacity.

During peak hours, movies were taken at critical locations along the Expressway and at on-ramp merging areas. These movies showed the merging problems, build-ups of congestion, and the subsequent reductions in capacity. It was possible to measure speeds and volumes from these movies.

Mechanical counts of volumes on each ramp and between each interchange were made. These were supplemented by manual counts of vehicle classification and lane distribution.

Radar speed distribution measurements were made between interchanges at points corresponding to manual volume counts. Travel time studies were made in peak and off-peak hours, recording the elapsed distance every minute to precisely pinpoint areas of congestion and draw a speed-distance curve for the entire Expressway. Travel time studies were repeated in June to determine the effect of slightly higher volumes.

●THIS PAPER is a summary of a detailed report submitted to the Pennsylvania Department of Highways for determining the extent of existing and future deficiencies on the Schuylkill Expressway and the nature of improvements to correct these deficiencies.

Studies included manual and mechanical volume counts, radar speed surveys, time delay studies, lane distribution, vehicle classification, ramp studies, a review of accident experience, and motion pictures of peak-hour Expressway conditions.

These studies provided the factual data for analysis of Expressway deficiencies, traffic demands and operations, and guided determinations for immediate and future improvements designed to expedite traffic flow with increased safety.

The scope and intent of this paper is not to cover fully all the details of the report submitted to the Pennsylvania Department of Highways, but to summarize the types of studies made, and more specifically to point out the usefulness of the techniques used in the ramp studies for acquiring data to determine the need for ramp corrections.

The Schuylkill Expressway (Fig. 1) is Philadelphia's first radial limited-access highway and consequently is subjected to tremendous peak-hour volumes and subsequent congestion. Following its completion, the Expressway was made a part of the State's interstate highway system, designated as Interstate 80S and 680. Its termini are the Pennsylvania Turnpike on the west and the Walt Whitman Bridge to New Jersey on the east. It provides connections with all major arterial streets and highways between the Turnpike and Bridge and is one of the principal means of access to center city Philadelphia. Starting from its northern connection with the Pennsylvania Turnpike, the Expressway was constructed and opened in stages beginning in 1950.

The Expressway is adjacent, and substantially parallel, to the West River and East River Drives, between City Avenue and Spring Garden Street interchanges. It is the only limited-access facility in the area and, as a consequence, has diverted substantial traffic volumes from each of the two River Drives, as well as from other routes to and from, or through, center city. The generally superior character of the Expressway makes it particularly attractive to commuter traffic, traveling daily between center city and the suburbs. It, therefore, develops peak-hour morning and evening volumes, ranging from 2 to 3 times average midday volumes.

TRAFFIC

Approximately 165,000 vehicles use the Expressway on an average weekday in 1960. Highest volumes are in that section of the Expressway between Spring Garden Street and Girard Avenue. Average 1960 weekday volumes in this section are 88,666 vehicles.

The highest one-directional volume of traffic within a 60-min period during the study was recorded outbound between 4:30 and 5:30 p.m., between Spring Garden Street and Girard Avenue—5,720 vehicles or an average of slightly more than 1,900 vehicles per lane in this three-lane (directional) section of highway. A simultaneous record of the lane distribution of traffic at this location showed 2,489 vehicles westbound in the median lane.

The Expressway interchange with the highest volume of traffic is the connection to and from Vine Street—53,361 vehicles entered or left the Expressway at this point. Of this number, 38,492 were to and from the west, and 14,869 were to and from the east.

Between Vine Street and City Avenue interchanges, the 1960 peak-hour volumes of traffic exceed the practical capacity of the Expressway. During commuter periods, particularly the evening homebound rush hours, the pressure of traffic on this section of the Expressway is such that vehicle spacing forces operating speeds considerably below the 50-mph posted speed limit. During those times, the operating sensitivity is such that the slightest disruption of flow, caused by an incident such as a vehicle breakdown, results in stop-and-go operations over long distances and for considerable periods of time after the occurrence has been cleared.

INTERCHANGE CAPACITY

With few exceptions, interchange capacity is limited by mandatory stops at ramp entrances to the Expressway; made necessary because of inadequate acceleration lanes. Yield signs have replaced the stop signs since this study was completed. Off-ramp operations are often hindered by surface street traffic controls, inadequate storage, and lack of proper deceleration lanes. These conditions are incompatible with modern limited-access highway design.

Studies indicate that on-ramp capacity can be increased up to 60 percent by providing adequate acceleration lanes.

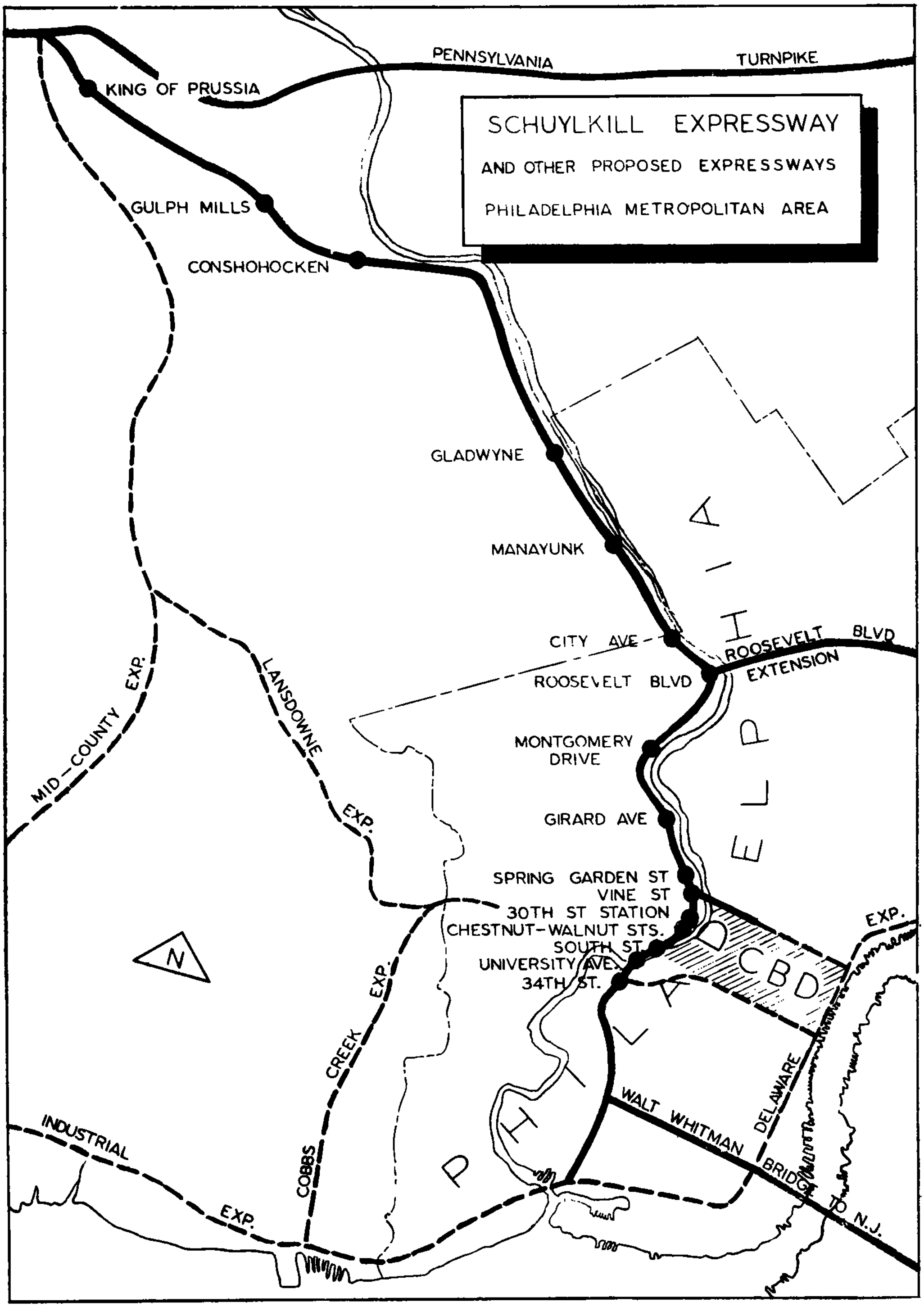
SCHUYLKILL EXPRESSWAY
AND OTHER PROPOSED EXPRESSWAYS
PHILADELPHIA METROPOLITAN AREA
PENNSYLVANIA TURNPIKE
KING OF PRUSSIA
GULPH MILLS
CONSHOHOCKEN
GLADWYNE
MANAYUNK
CITY AVE
ROOSEVELT BLVD
ROOSEVELT BLVD EXTENSION
MONTGOMERY DRIVE
GIRARD AVE
SPRING GARDEN ST
VINE ST
30TH ST STATION
CHESTNUT-WALNUT STS.
SOUTH ST.
UNIVERSITY AVE.
34TH ST.
CBD
PHILADELPHIA
MID-COUNTY EXP.
LANSDOWNE EXP.
COBBS CREEK EXP.
INDUSTRIAL EXP.
DELAWARE EXP.
WALT WHITMAN BRIDGE TO N.J.
N

Figure 1.

ACCIDENTS

Analysis of reports of accidents occurring on the Expressway indicate a fatality rate—based on exposure—greater than that of the Pennsylvania Turnpike and the New Jersey Turnpike, the two existing limited-access facilities transversing the Philadelphia metropolitan area.

	Year	Deaths Per 100 Million Vehicle-Miles
Schuylkill Expressway	1959	4.1
Pennsylvania Turnpike	1959	3.7
New Jersey Turnpike	1959	1.5

TRAFFIC DISTRIBUTION, PARALLEL ROADS

On an average weekday, 8,800 vehicles travel inbound along both sides of the Schuylkill River during the morning eastbound peak hour. In the maximum load area, this volume moves along seven eastbound lanes of roadway—three on the Schuylkill Expressway and two each on the East and West River Drives. The westbound evening peak hour is only slightly less—8,700.

Eastbound, the three Expressway lanes are used by 56.8 percent of this traffic and the four River Drive lanes the remainder. Westbound, the distribution is 65.5 percent on the Expressway and 34.5 percent on the River Drives.

FUTURE TRAFFIC

It is anticipated that traffic volume in 1975 will be 45 percent higher than at present.

In the maximum load section—between the Girard Avenue and Spring Garden Street Interchanges—1975 traffic will increase from 88,666 to an estimated average daily volume of 128,300.

This estimate gives effect to the influence of a fully interconnected Expressway system in Metropolitan Philadelphia. If this system is not completed by 1975, the demand on the Expressway will be even greater.

Design hour estimates are based on peak hour and major directional percentages of 10 percent and 55 percent west of the Gladwyne Interchange, 10 percent and 60 percent from Gladwyne to the City Avenue Interchange, 9 percent and 65 percent between City Avenue and the Vine Street Ramps and east of Vine Street, 10 percent and 55 percent, respectively.

TRAFFIC VOLUME STUDIES

Traffic volumes on the Expressway, ramps and feeder roads were determined by manual and machine counts during February and March 1960. Machine counts were made at 100 locations and manual counts at 19 locations, nine of which also served as a check on machine counts.

Surface street volumes and turning movements at several locations near the entrance to, or exit from, Expressway ramps were made to determine directional flow of traffic at those points.

Each machine count was made for a minimum of one week; thus the relationship of one weekday to another was established as well as the average weekday.

Vehicle classification and lane distribution manual counts were made at nine locations along the Expressway. These counts were conducted from 7:00 to 10:00 a.m., 11:00 a.m. to 3:00 p.m. and from 4:00 to 7:00 p.m. at each location. Checkers were assigned to each lane and recorded by ½-hr periods the volume in that lane segregated by vehicle type.

Checks on the reliability of machine counts, unadjusted for dual rear-axle vehicles, indicate a satisfactory degree of accuracy—less than 3 percent difference between simultaneous machine and manual counts.

The day-to-day variation in traffic on the Expressway, Monday through Thursday is slight. Friday is consistently the heaviest traveled weekday and normally presents the maximum traffic condition. Weekends show a substantial drop in volume from the average weekday.

Vehicle Classification

In the classification counts made at nine locations on the Expressway, vehicles were classified as passenger cars, light trucks (panel, pickup, etc.), heavy trucks, tractor-trailers and buses.

During the 10-hr period in which vehicle classification checks were made, heavy trucks and tractor-trailer combinations comprised approximately 12 percent to 16 percent of the total traffic west of the City Avenue Interchange, 6 percent to 8.5 percent between the City Avenue and Vine Street Interchanges, and from 9 percent to 14 percent east of the Vine Street Interchange.

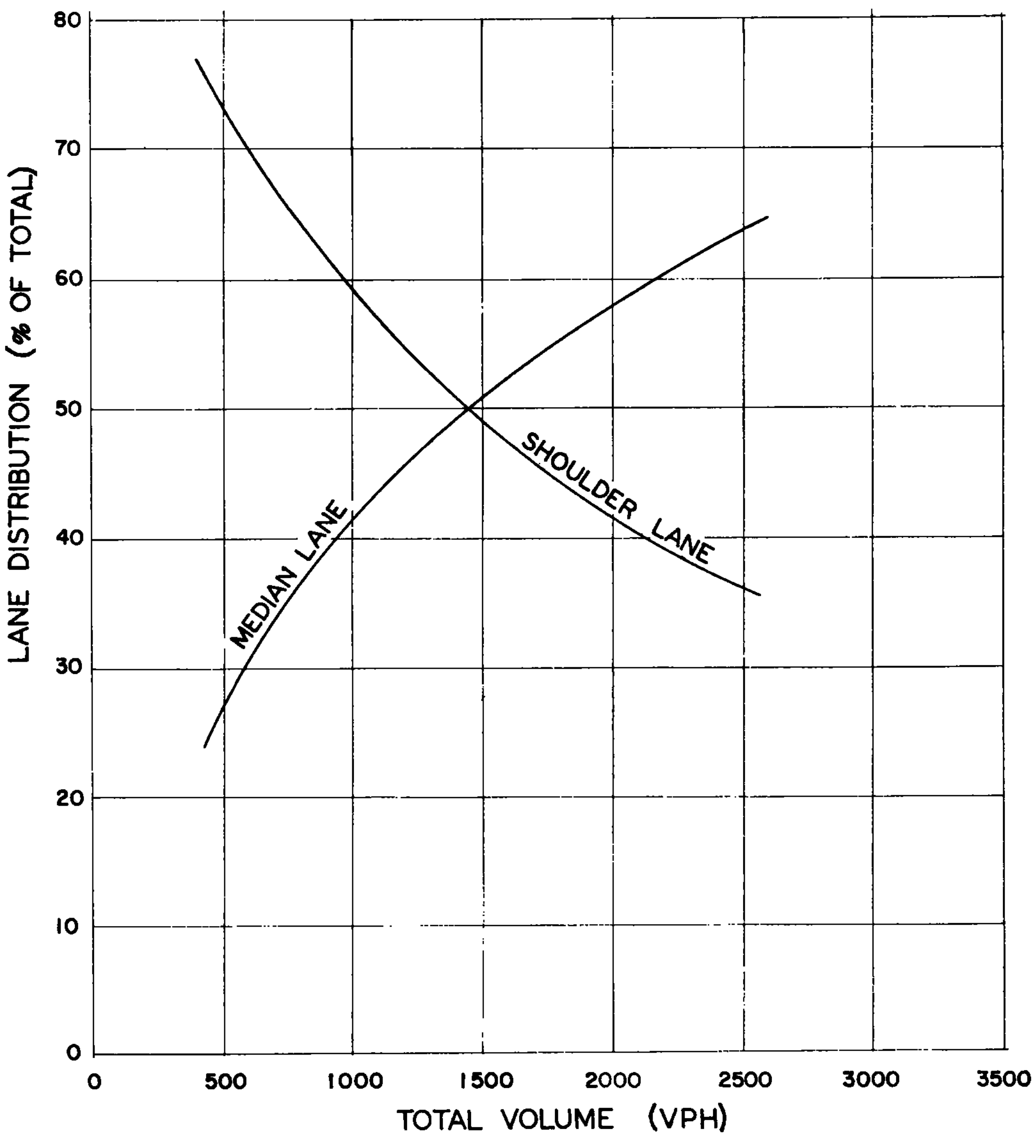

Figure 2. Schuylkill Expressway, lane distribution (2-lane section).

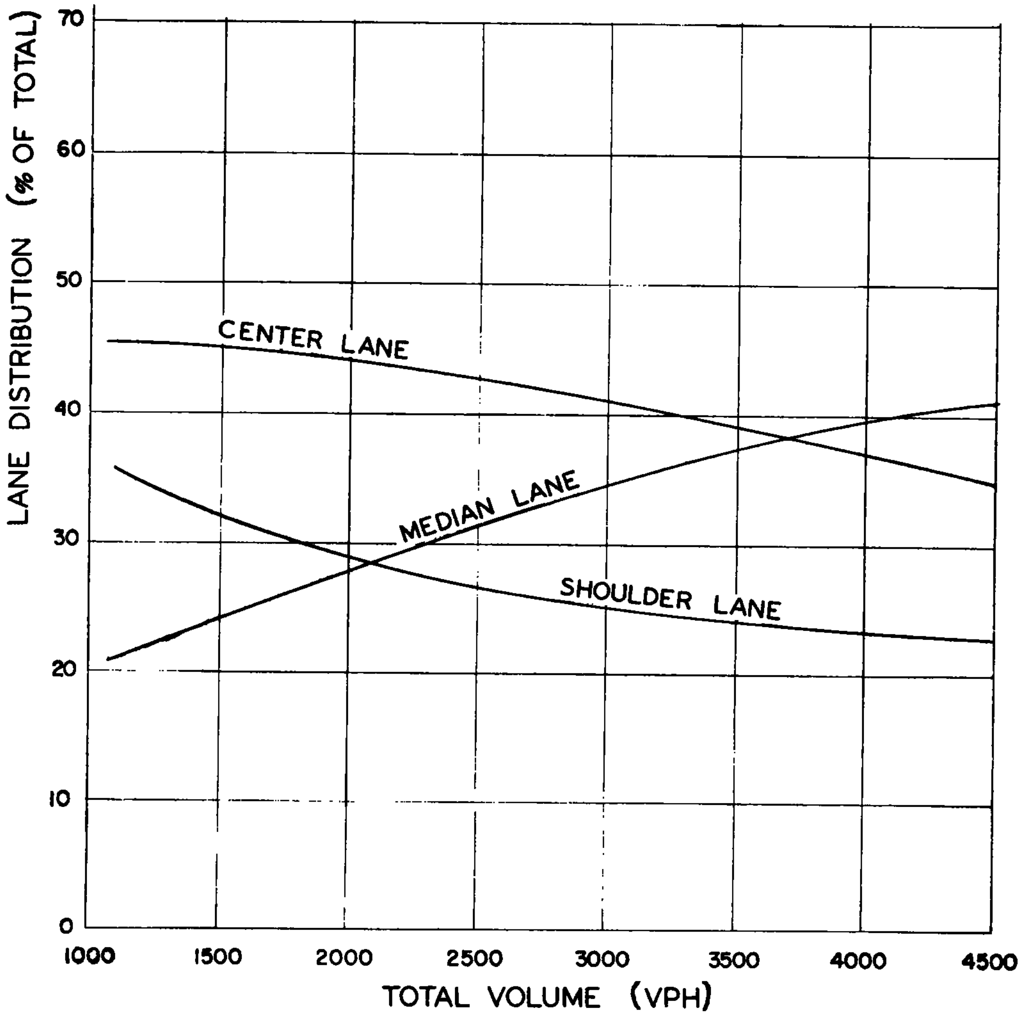

Figure 3. Schuylkill Expressway, lane distribution (3-lane section).

Lane Distribution

Figure 2 shows the average distribution of vehicles in the median and shoulder lanes in the two-lane sections of the Expressway in relation to total volume. Figure 3 shows comparable data for the three-lane sections.

Lane distribution in each direction was determined for heavy trucks and also for total vehicles during midday, a. m. and p. m. peak periods.

Radar Speed Studies

Vehicle speeds were measured by radar speed meters at 11 locations on the Expressway. Nine of these checks were made at the same locations as the vehicle classification and lane distribution counts. By measuring speeds and volumes simultaneously a close control of the speed-check sample was possible and major fluctuations in the speed-volume relationship could be recorded.

Samples were designed to yield average speeds which would be accurate within ± 1 mph.

At each location, speeds were measured by lane and vehicle type in the morning from 7:00 a. m. to 9:00 a. m., midday between 9:00 a. m. and 4:00 p. m. and in the evening from 4:00 p. m. to 6:00 p. m. Speeds were also recorded in both directions at all locations except those east of Vine Street where peak-hour speeds were recorded only in the direction of major flow.

Lane Speeds

Average speeds in the shoulder lane were found to be, in general 1 to 3 mph slower than the center or median lane. Speed observations of vehicles operating in the median lane of the three-lane sections could not be accurately recorded because of interference from vehicles in the other two lanes.

Speed Violations

The highest percentage of passenger car speed violators (13.9 percent above 50 mph and 2.1 percent above 55 mph was recorded for vehicles operating in both directions between City Avenue and Montgomery Drive, during the midday. This percentage reflects the change from 60 to 50 mph in the legal speed limit at City Avenue.

In general, automobile speeds are 5 to 7 miles faster than heavy trucks and tractor-trailer speeds west of City Avenue where the passenger vehicle limit is 60 mph and the truck limit 50 mph. Where the speed is the same for both vehicle types (50 mph), truck speeds are from 1 to 3 mph lower than passenger vehicles.

Operating Speeds

To measure speed variations and time consumed for single trips during commuter hours and midday, a series of operating speed runs were made by the average vehicle method.

METHOD OF STUDY

At the end of each 60-sec interval, a recorder noted the odometer reading. This method of recording resulted in an adequate number of readings per mile in free-flowing sections, and more importantly, increased the number of readings for each mile of travel in congested areas.

All runs were made on weekdays during the month of March and included both directions over the entire length of the Expressway.

Midday Studies

During off-peak hours, the only deterrent to high speeds is the enforcement of the posted speed limits. The average over-all speeds are 50.6 mph eastbound and 50.9 mph westbound. The average midday running time in either direction for the entire length of the Expressway is under 24 min.

Peak-Hour Studies

Average eastbound speeds between 8:00 and 9:00 a.m. are 40.3 mph; 28 percent below the weighted average posted speed limits, and 21 percent below average midday speeds. Westbound in the evening peak, speeds are of the same order, averaging 40.1 mph.

Speed and Delay

Average running time between King of Prussia and Passyunk Avenue is 24 min in either direction. During commuter hours, 30 min is required on the average. The maximum observed eastbound time was 35.6 min. The westbound maximum was 42.7 min, largely resulting from the "squeeze left" (3-lane to 2-lane transition section).

The critical section of the Expressway, between the Gladwyne and Vine Street Interchanges comprises 40 percent of the Expressway length, and accounts for 85 percent of the commuter hour lost time due to congestion. Time lost in commuter periods due to congestion is computed as the differential between midday and commuter period times.

RAMP CAPACITY STUDIES

Detailed studies were made at four heavily traveled on-ramps to establish quantitatively the extent to which present geometrics and regulatory devices tend to depress ramp capacities.

Specifically, the purpose of these studies was to determine: (a) capacities of on-ramps as presently designed; (b) delays to ramp vehicles; (c) relationship between ramp capacities and other operational variables such as Expressway speeds, shoulder lane volumes, frequency of shoulder lane gaps of various lengths and the characteristics of shoulder lane traffic; and, (d) criteria for the justification of improved ramp geometrics.

Procedure

The four ramps that were selected for study were among the most heavily traveled on the Expressway.

They were located at four contiguous interchanges, as follows, beginning at the west: (a) eastbound at Gladwyne Interchange; (b) eastbound at Manayunk Interchange; (c) westbound at City Avenue; and (d) eastbound at Montgomery Drive. The periods in which the studies were conducted were those during which the ramps were under maximum pressure. Thus, in most cases, vehicles were constantly stored on the ramps waiting acceptable Expressway gaps. At each ramp, data were collected for three successive periods approximating 15 to 20 min each, with breaks of 3 to 5 min between each period.

A team of five men was required, located as follows (Fig. 4): (a) two men at the ramp nose to record shoulder lane headways and merging vehicles; (b) two men on the Expressway approximately 200 to 300 ft in advance of the ramp nose to record by radar the speed of each shoulder lane vehicle; and, (c) one man "floating" on the ramp to record the time of the initial stop of each ramp vehicle and the number of vehicles then waiting on the ramp. Stop watches were used by the radar observers, by the men at the ramp nose and by the floating man, to enable accurate time observations. All watches were started simultaneously just before the beginning of each observation period.

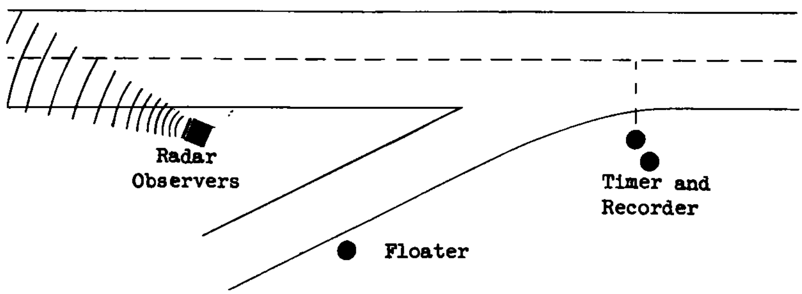

Figure 4.

One of the men at the nose of the ramp observed the exact second that each shoulder lane vehicle and each ramp vehicle reached the point where the ramp and Expressway merge; the other man recorded these data. Figure 5 shows the form used.

Radar speeds of each shoulder lane vehicle were recorded and classified, to be matched with vehicles recorded at the ramp nose. Figure 6 shows the form used for this purpose.

Figure 7 was used to record observations by the floating observer on the ramp.

Vehicle types were recorded at all locations to facilitate "matching" the entering and exiting recordings.

At the end of each study period, data sheets were collected and the stop watches were again synchronized for the start of the next period.

SCHUYLKILL EXPRESSWAY (PDH)

SHOULDER LANE HEADWAY - RAMP MERGING

Interchange ______________

Shoulder Lane ________ Bound Grade ________

Ramp ON OFF Length ________

Grade ______ Date ________

Weather ______________

Vehicle Classification

S = Small Car (Exc. Rambler Size)
W = Station Wagon
C = Cars other than S or W
P = Pickup
T = Truck
I = Tractor Trailer
B = Bus

Time AM PM	Shoulder Lane			Ramp Veh.	
	Time Sec.	Merge Sec.	Head-way Sec.	Wait-ing as 1st Veh. Sec.	Total Wait-ing Time Sec.

Time AM PM	Shoulder Lane			Ramp Veh.	
	Time Sec.	Merge Sec.	Head-way Sec.	Wait-ing as 1st Veh. Sec.	Total Wait-ing Time Sec.

Figure 5.

SCHUYLKILL EXPRESSWAY (PDH)

SHOULDER LANE VEHICULAR SPEED - BEFORE RAMP

Interchange ____________________

Shoulder Lane ________ Bound Grade ____________

Ramp On Off

Date ____________________

Weather ____________________

Vehicle Classification

T = Truck

I = Tractor Trailer

B = Bus

Time AM PM	Time Sec.	Speed MPH	Time AM PM	Time Sec.	Speed MPH	Time AM PM	Time Sec.	Speed MPH	Time AM PM	Time Sec.	Speed MPH

Figure 6.

SCHUYLKILL EXPRESSWAY (PDH)

RAMP VEHICLE DELAY

Interchange ____________________

Shoulder Lane __________ Bound Grade _________

Ramp On Off Length

Grade Stop Sign No Sign

Vehicle Classification

S = Small Car (Excl. Rambler Size)
W = Station Wagon
C = Cars Other Than S or W
P = Pickup
T = Truck
B = Bus
I = Tractor Trailer

Time AM PM	Time of First Stop Sec.	No. of Veh. in Front	Time AM PM	Time of First Stop Sec.	No. of Veh. in Front	Time AM PM	Time of First Stop Sec.	No. of Veh. in Front	Time AM PM	Time of First Stop Sec.	No. of Veh. in Front

Figure 7.

Preliminary summarization of field sheets yielded these data: (a) shoulder lane gap distribution; (b) distribution (by time length) of the accepted and rejected gaps; (c) distribution of gaps accepted by a queue of cars (for example, three cars accepting a single gap); (d) waiting time on ramp before merging; (e) waiting time on ramp as first vehicle in lane; and (f) speeds of lead and trail vehicles for each gap.

Delays to Ramp Vehicles

Figure 8 shows the delay to ramp vehicles as a function of their place in line on arrival at the ramp. The average delay ranged from 16.4 sec at the Gladwyne ramp to 33.3 sec per vehicle at the City Avenue ramp.

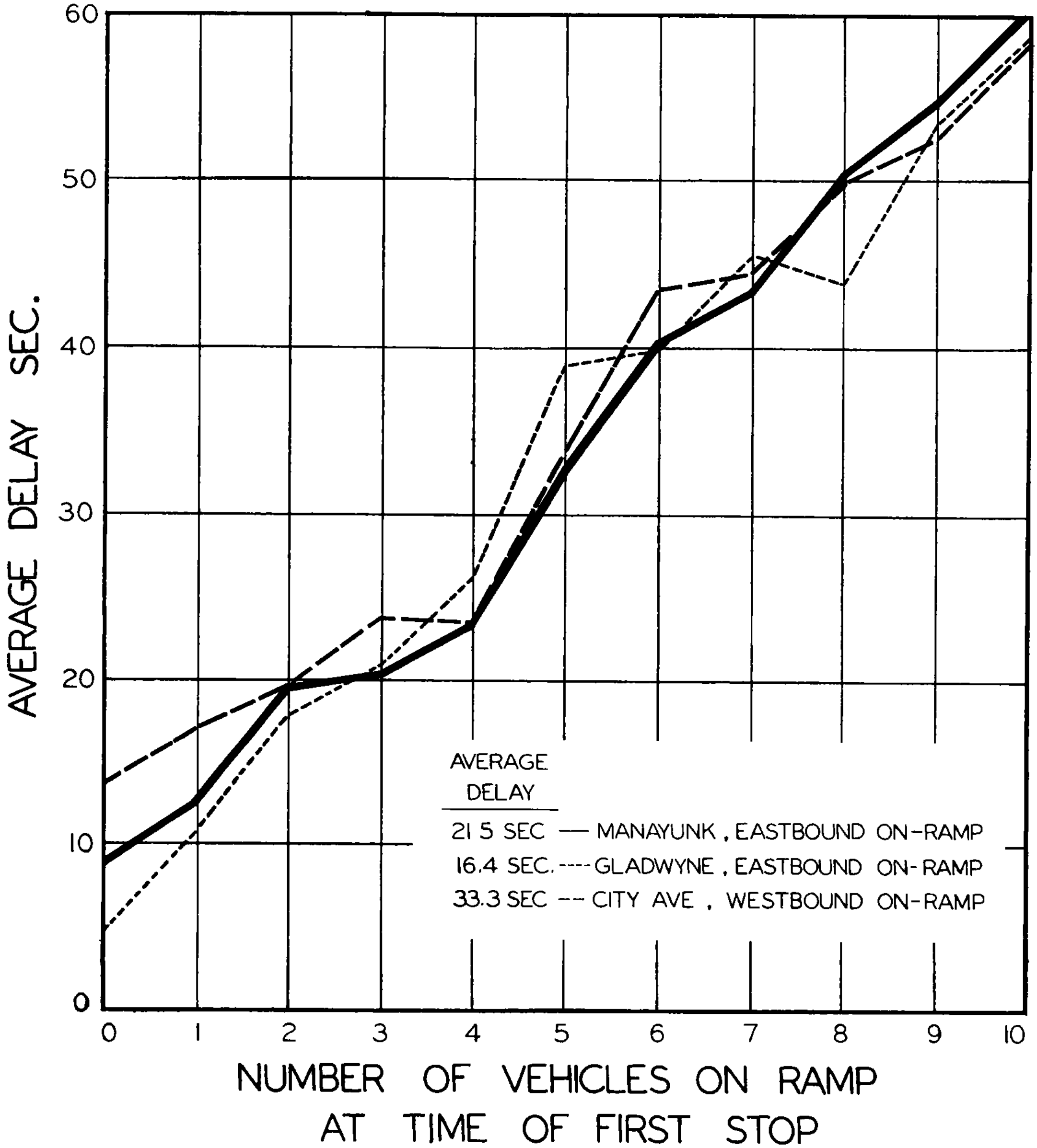

Figure 8. Average vehicle delay.

The delay curves of the on-ramps are similar; the maximum deviation being approximately 8 sec with only one vehicle on the ramp. Very few observations were obtained of delays over 60 sec.

Data for the Montgomery Drive on-ramp are not plotted on Figure 8 because delays were so long that the line of waiting vehicles stretched out of sight and made it impossible to record data properly. However, several cars were "clocked" from the time they first came into line until they moved into the shoulder lane. An average delay of 2.1 min was computed from eight observations. This condition is continuous for approximately 45 min to 1 hr each morning.

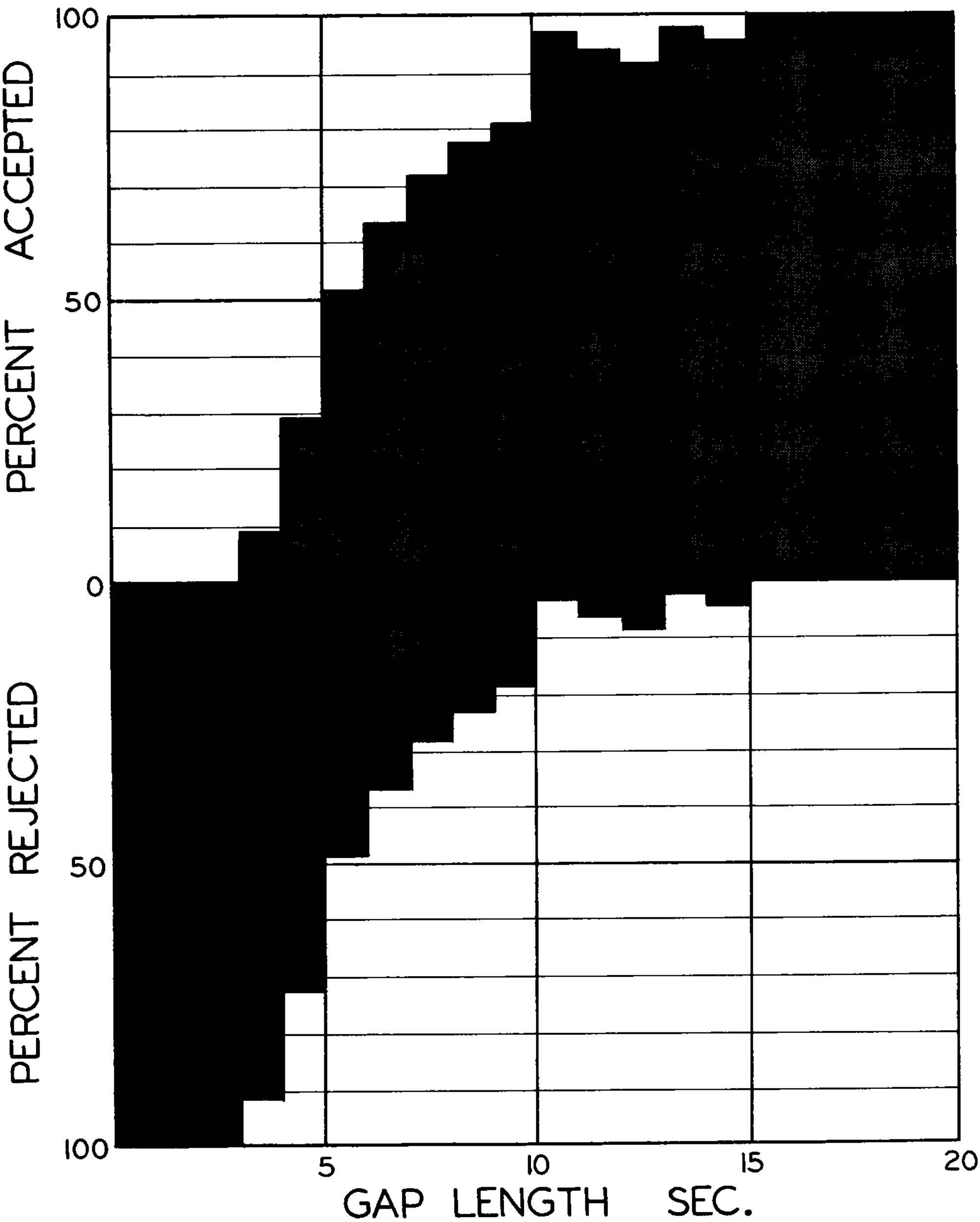

Figure 9. Gap acceptance and rejection composite on-ramps with stop signs (1,100 observations).

Ramp Capacities

The studies yielded 1,100 observations of gaps which were accepted or rejected by ramp vehicles. Figure 9 shows a composite summary of gap acceptance at these ramps. The plotted points demonstrate a close fit to parabolic curves. A correlation analysis of the percent of rejected gaps yielded a coefficient of correlation of -0.99 with the equation:

$$\log R = 2.377 - 0.114T$$

in which

R = the percent of rejected gaps
T = the gap length in seconds

The 50th percentile of accepted gaps is at 6 sec. This corresponds closely to a previous finding of 5 sec for stop sign locations (1).

Figure 10 illustrates the degree of acceptance of gaps by a queue of vehicles.

The data from Figure 10 are used as the basis for Figure 11, which illustrates the relationship between the length of gap and the number of vehicles per gap. The coefficient of correlation for Figure 11 is 0.94.

After establishing the number of vehicles that will accept each gap, only the frequency of occurrence of each gap length in a given time interval need be known to predict the number of ramp vehicles which will enter the Expressway. Because the hourly rate of vehicle flow in the shoulder lane ranged from 300 to 800 when gap distributions were determined, it was decided to use the Poisson distribution to compute gap distributions in and beyond this range. Several chi-square tests of computed versus actual gap distributions showed very close fits. No gap distributions for hourly flows above 1,100 vehicles per hour were computed inasmuch as randomness ceases to function at about this volume. As an example, consider the shoulder lane flowing at 800 vehicles per hour. Then, by a computation similar to that in Table 1 ramp capacities were computed for various shoulder lane volumes and plotted in Figure 12.

Data for the on-ramp with adequate acceleration lane curve are based primarily on studies made in California (2).

Table 2 compares Expressway ramp capacities—vehicles per hour—of an inadequate acceleration lane having a stop sign at the Expressway entrance with capacities of ramps having an adequate acceleration lane and no stop sign, for various shoulder lane volumes.

Off-Ramps

Specific problems exist at several off-ramps, due primarily to conditions at the local street end of the ramps, in addition to insufficient deceleration lanes. During the p.m. peak hour, westbound traffic leaving the Expressway at City Avenue and Manayunk often are stopped on the Expressway as the ramps at these locations are full.

Recommendations to improve these conditions were made at each critical location.

As an example of the technique used to apply the ramp study curves, the following is a typical interchange analysis.

Manayunk Interchange Recommendation

One of the most congested interchanges is the Manayunk Interchange. The present and future peak-hour volumes for Expressway lanes and the eastbound on-ramp are given in Table 3. The practical ramp capacity under present conditions (inadequate acceleration lane with stop sign) and with adequate acceleration lane based on the ramp study data is shown in Figure 12.

On-Ramp C is at capacity in 1960 and by providing an adequate acceleration lane, the ramp will not reach capacity again until 1973. If a third lane is added to the Expressway at that time, the ramp capacity will extend well beyond 1975.

Immediate lengthening of the acceleration and deceleration lanes at this interchange (Fig. 13) was recommended. In addition, it was recommended that Ramp D be widened to two lanes.

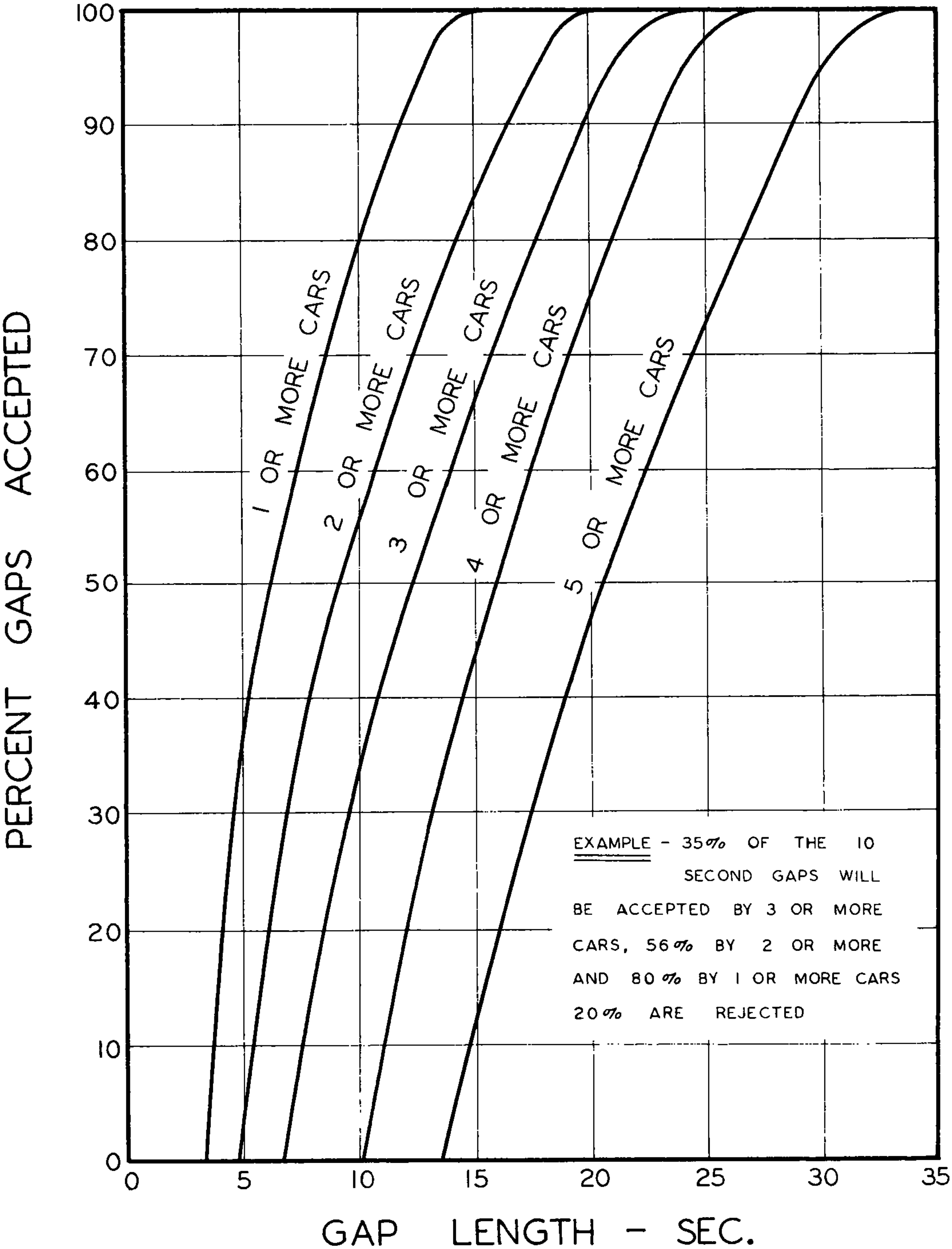

Figure 10. Gap acceptance by queues of vehicles.

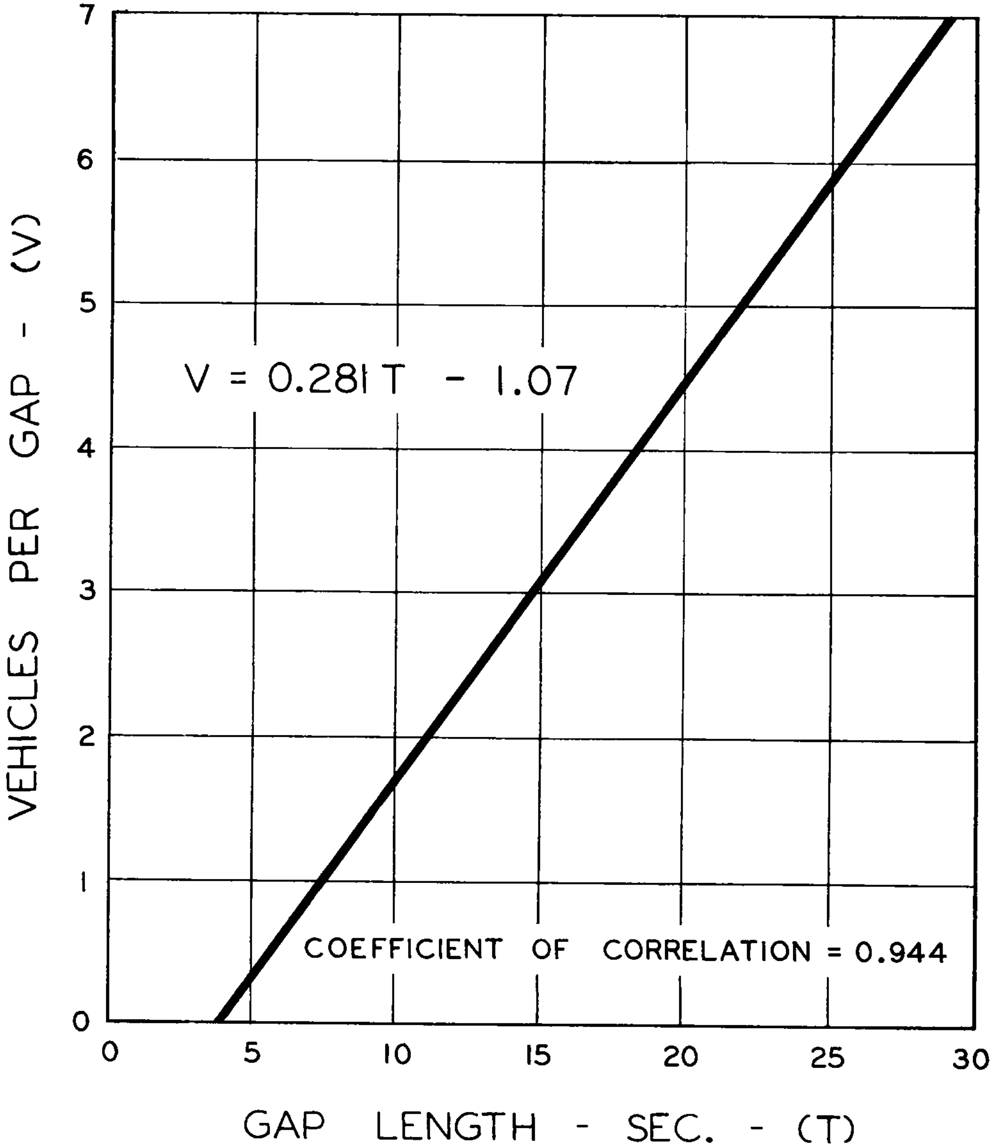

Figure 11. Vehicles per gap.

TABLE 1

Gap Length, T (sec)	Calc. No. of Gaps of T sec	Veh. (no.) Per Gap*	Veh. (no.) Total
0	-	-	0
1	159	-	0
2	127	-	0
3	103	-	0
4	82	0.05	4
5	65	0.33	21
6	53	0.61	32
7	42	0.89	37
8	34	1.17	40
9	27	1.45	39
10	22	1.73	38
11	17	2.01	34
12	14	2.30	32
13	10	2.58	26
14	10	2.86	29
15	7	3.14	22
16	6	3.42	21
17	5	3.70	19
18	4	3.98	16
19	3	4.27	13
20	2	4.55	9
21	2	4.83	10
22	1	5.11	5
23	1	5.39	5
24	1	5.67	6
25	1	5.95	6
26	1	6.24	6
27	0	6.52	0
28	0	6.80	0
29	0	7.08	0
30	0	7.36	0
30	1	8.77	9
	800	Ramp Capacity=	479 VPH

*Data from Figure 11.

TABLE 2

Shoulder Lane Volume	Ramp Capacity: Inadequate Acceleration Lane with Stop Sign	Ramp Capacity: With Adequate Acceleration Lane	% Increase
200	820	1,330	62
500	660	1,060	61
800	500	800	60
1,100	340	540	59
1,400	175	280	60

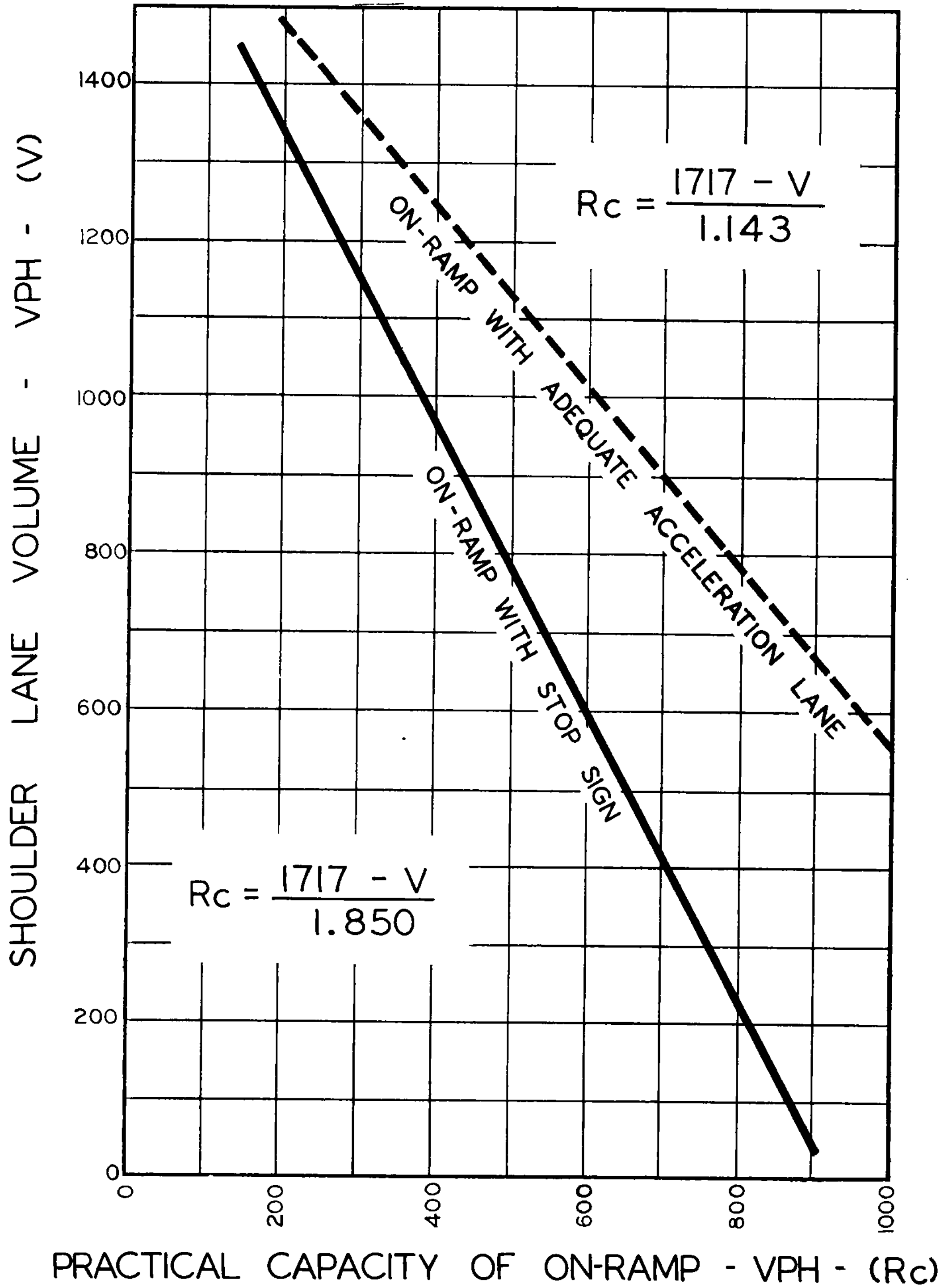

Figure 12. Practical capacity of on-ramps related to shoulder lane volume.

TABLE 3

No. of Exp. Lanes	Year	Expressway DHV				Ramp DHV	Practical Ramp Capacity	
		Total	Median	Center	Shoulder		With Stop Sign	With Acc. Lane
2	1960	2,286	1,606	-	680	561	560	910
2	1975	2,680	1,720	-	960	700	410	665
3	1975	2,680	800	1,100	700	700	540	870

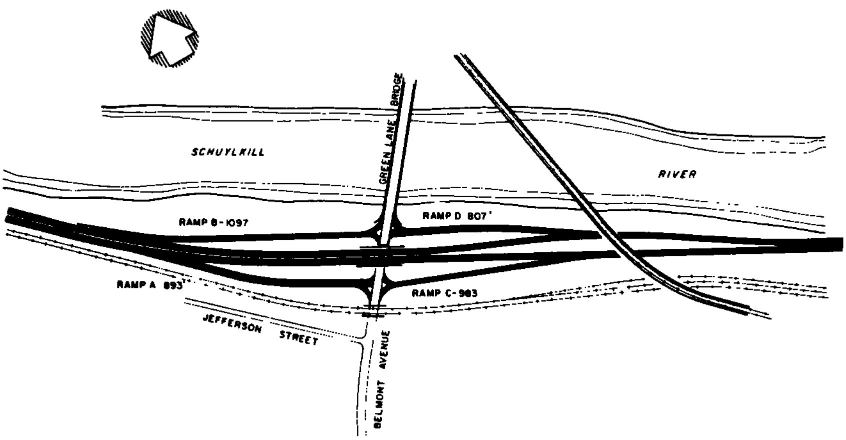

Figure 13. Manayunk Interchange.

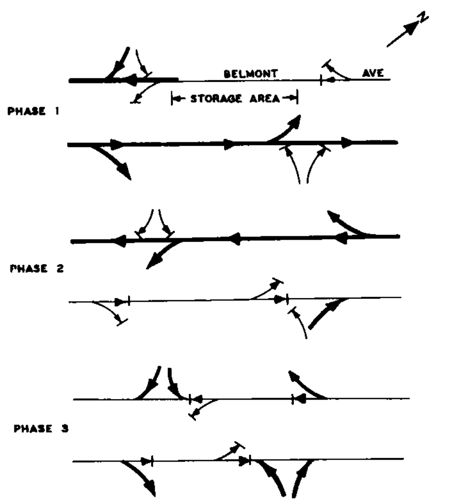

Figure 14. Phasing diagram of Manayunk Interchange.

To provide needed capacity including left turn storage, the widening of Belmont Avenue from four to six lanes was recommended.

To provide increased capacity on Green Lane Bridge, it was recommended that the bridge roadway be widened to five lanes, three of which would operate in the major direction. This may be done by eliminating the sidewalk on one side of the bridge and reducing the sidewalk on the other side to 4 or 5 ft.

Left turn channels from Ramps A and D would be widened sufficiently to permit turns from these ramps to be made in two lanes.

A traffic actuated progressive signal system would be installed to control traffic movements between the interchange ramps and Belmont Avenue, including Jefferson Street, and at Green Lane and Main Street in Manayunk.

It was recommended that the signals at

the ramp ends and Belmont Avenue be three-phase (Fig. 14). Three-phase operation will make possible the clearing of the limited storage area between the ramps before through movement begins and will increase the capacity for right turns from the ramps by permitting this movement during two of the three phases.

The studies and analyses summarized in this paper led to the following additional recommendations: (a) additional lanes, (b) adequate acceleration and deceleration lanes, (c) median barrier, (d) fencing to prevent pedestrian crossings, (e) lighting at least at all interchanges where such does not now exist, (f) a 55-mph "transition" speed limit between existing 60-mph and 50-mph sections, (g) minimum 10-ft shoulder width, and (h) restricting traffic by ramp closings when necessary.

REFERENCES

1. Bureau of Highway Traffic, Yale University, Technical Report 4, p. 69, Table XII.
2. Moskowitz, K., "Research on Operating Characteristics of Freeways." ITE Proc. (1956).