Squirrel Hill Tunnel Operations Study

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• THIS PAPER contains the results of a traffic operations study of the westbound Penn-Lincoln Parkway in the vicinity of the Squirrel Hill Tunnel in Pittsburgh. The primary purpose of this study was to determine means of improving and maintaining optimum traffic operations during the presently congested morning peak period. It was also the purpose of this study to formulate freeway study techniques and to develop a better understanding of freeway characteristics to aid in improving traffic operations on other congested controlled access facilities.

The study employed photographic techniques which permitted the simultaneous observation and measurement of traffic characteristics at locations upstream, downstream, and at critical controlling points for intervals of time before, during, and after congestion. The use of the photographic technique has also resulted in a permanent record of traffic operations that can be reviewed qualitatively and quantitatively by technical personnel and that can be shown to civic groups as public information.

The study results include time and distance profiles of speed, volume, and density characteristics and the interrelationships among these characteristics. The analysis permitted the comparison of traffic characteristics between lanes and the estimation of traffic demand. The results of an investigation to determine the effect of trucks on time headways are included, and travel time studies were conducted.

The interpretation of the results of the study included locating critical points, determining causes of congestion and reduction in capacity, investigating means for improvement, and estimating benefits of such improvements. Investigation of possible means for improvement included consideration for ramp redesign, reversible lane operations, truck restrictions, ramp closures, metering ramp and/or freeway flow, and permitting lane changing in the tunnel. A general description of a traffic control system for maintaining optimum conditions during congested periods is included.

The final part of the paper describes the action taken by the Pennsylvania Department of Highways as a result of the operations study. This included the use of reversible lane operation, ramp closure and further investigation of a traffic metering system and road construction.

STUDY OBJECTIVES

The immediate objectives of this study were (a) to locate critical point or points controlling traffic operations, (b) to ascertain the cause or causes of congestion and reduction in capacity, (c) to determine possible means of improving parkway operations, and (d) to predict the effect of improvement on parkway operations.

The longer-range objectives of the proposed study were (a) to develop freeway study techniques, (b) to provide information for evaluating the effect of certain design features on freeway operations, and (c) to contribute to a better understanding of traffic behavior on freeways for the improvement of operation on this and other freeways.

BACKGROUND

The Penn-Lincoln Parkway is an east-west controlled-access facility that serves the Greater Pittsburgh Area and that was opened to traffic in 1953. The Parkway extends from the west in the vicinity of the Greater Pittsburgh Airport through the Fort Pitt Tunnel, across the Monongahela River on the Fort Pitt Bridge, along the southern fringe of the Golden Triangle, through the Squirrel Hill Tunnel, and to the east to connect with major highways to Harrisburg, Philadelphia, and beyond (see Fig. 1).

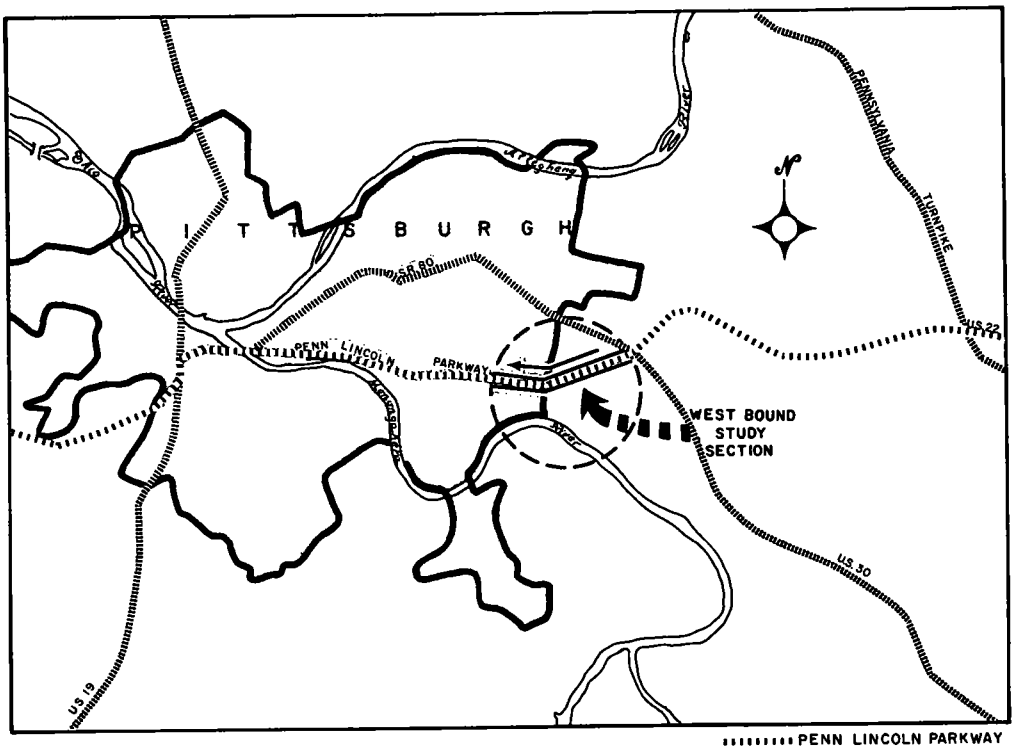


Figure 1. Penn-Lincoln Parkway in Greater Pittsburgh.

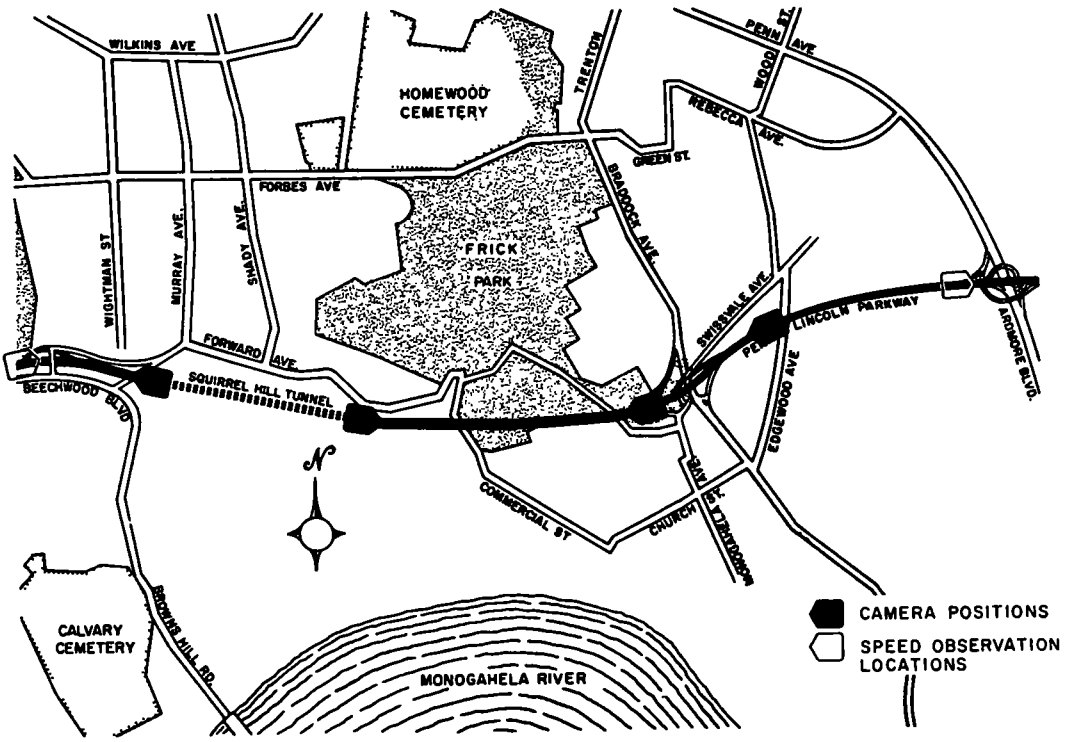


Figure 2. Study section on Penn-Lincoln Parkway.

The 3½-mi study section extends from Ardmore Boulevard on the east to Greenfield Bridge on the west, as shown in Figure 2, and includes the Squirrel Hill Tunnel. There are two westbound lanes on the study section, separated from eastbound traffic by a narrow median. The route is on a rolling profile with a 2 to 5 percent downgrade from Ardmore Boulevard to Braddock Avenue, a 1 to 2½ percent upgrade from Braddock Avenue through the Tunnel, and then a 4 to 5 percent downgrade. There are two on-ramps at Ardmore Boulevard, two on-ramps and an off-ramp at Braddock Avenue, an off-ramp near the exit from the Squirrel Hill Tunnel, and an on-ramp near the Greenfield Bridge where the roadway is widened to three westbound lanes. The design features receiving special attention were the proximity of two on-ramps at the foot of the 1.7-mi upgrade, the 1.7-mi upgrade, and the Squirrel Hill Tunnel near the crest.

The annual average daily traffic volume through the Squirrel Hill Tunnel has increased from 47,700 in 1957, to 56,300 in 1960. This traffic demand, particularly during the morning peak period in the westbound direction, has resulted in congestion that is of 1- to 2-hr duration and extends for distances of 2 to 3 mi each weekday morning.

Public reaction to this continuing problem demanded that prompt action be taken to reduce delay and decrease the accident potential on the approach to the Tunnel area. Considerable controversy existed as to the best method of meeting the situation.

TIME-LAPSE PHOTOGRAPHIC AND TRAVEL TIME STUDIES

Time-lapse photographic techniques were employed, and four intervalometer cameras were operated from selected ground locations along the study section (see Fig. 2). The camera locations were selected so that traffic flow at key portions downstream, upstream, and at the congestion points was recorded. At each location photographs were taken at a rate of 1 frame per sec for a 2-hr period (7 to 9 a.m.) for four normal weekdays (May 1 to 4, 1961). The 2-hr period included the photographing of traffic flow before, during, and after congestion.

A projector especially adapted for frame-by-frame analysis was employed to obtain volume, speed, and density on a per-lane basis and for 1-min intervals. Vehicle speeds and densities were sampled every 15 sec in each lane. Total volume, truck, volume, speed, and density measurements for each minute of the study, for each lane, for each camera location, and for two selected days (Wednesday and Friday, May 3 and 5) were punched on cards for machine analysis. Parkway volumes, percent trucks, and calculated densities were computed and punched on the same cards. Each card represents a 1-min interval at a particular camera for a specific day and there are 960 cards (2 days x 120 min x 4 cameras).

The specific analyses undertaken for the photographic data included speed-volume-density, profiles, speed-volume-density interrelationships, comparison of lane traffic characteristics, time headway distributions, and estimation of traffic demand.

Speed-Volume-Density Profiles

Time profiles of speeds, volumes, densities, and percent trucks for each of the four camera positions for May 3 (Wednesday) and May 5 (Friday) were prepared, and one such graph is shown as Figure 3. The two days of observations were placed on the same graph for each camera position, and indicate that traffic characteristics on the two days selected are very similar as to magnitudes and time of occurrences. Each plotted point represents 1 min of observation of a particular characteristic for the two westbound lanes, and the lines on the graphs indicate trends and are not mathematically fitted curves. The graphs indicate that periods of time before, during, and after congestion were analyzed, and that the data collection stations selected were located both upstream and downstream of congestion.

Distance profiles of speeds, volumes, densities, and percent trucks of May 3 (Wednesday) and May 5 (Friday) were prepared, and one such graph is shown as Figure 4. In addition to the four camera positions, speed measurements were obtained at a point upstream (Ardmore ramp overpass) and at a point downstream (Greenfield Bridge) and are shown on these graphs as locations 1 and 6 respectively. Each profile represents a 1-min interval, and five profiles are plotted on each sheet.

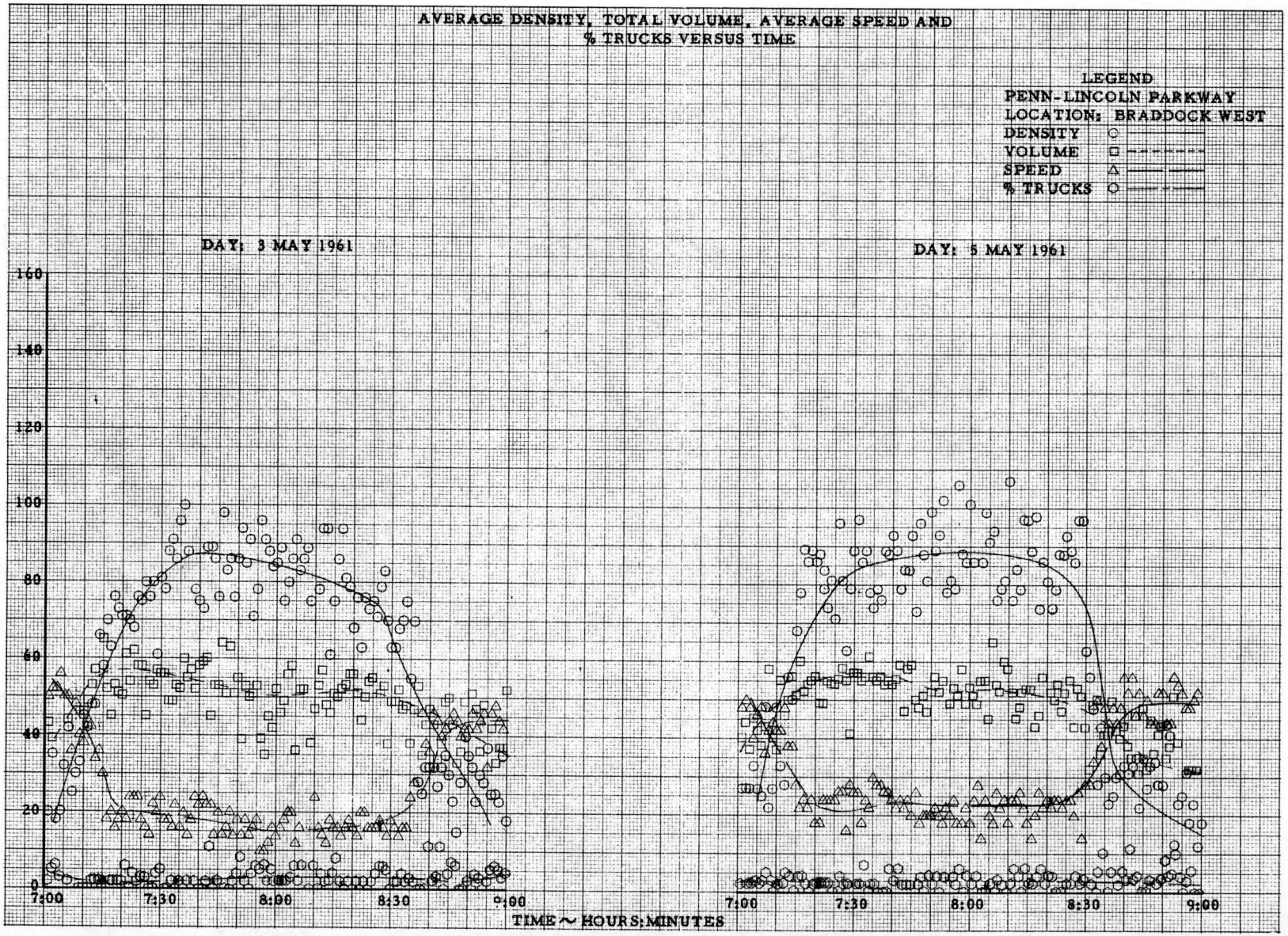


Figure 3. Sample of speed-volume-density time profiles

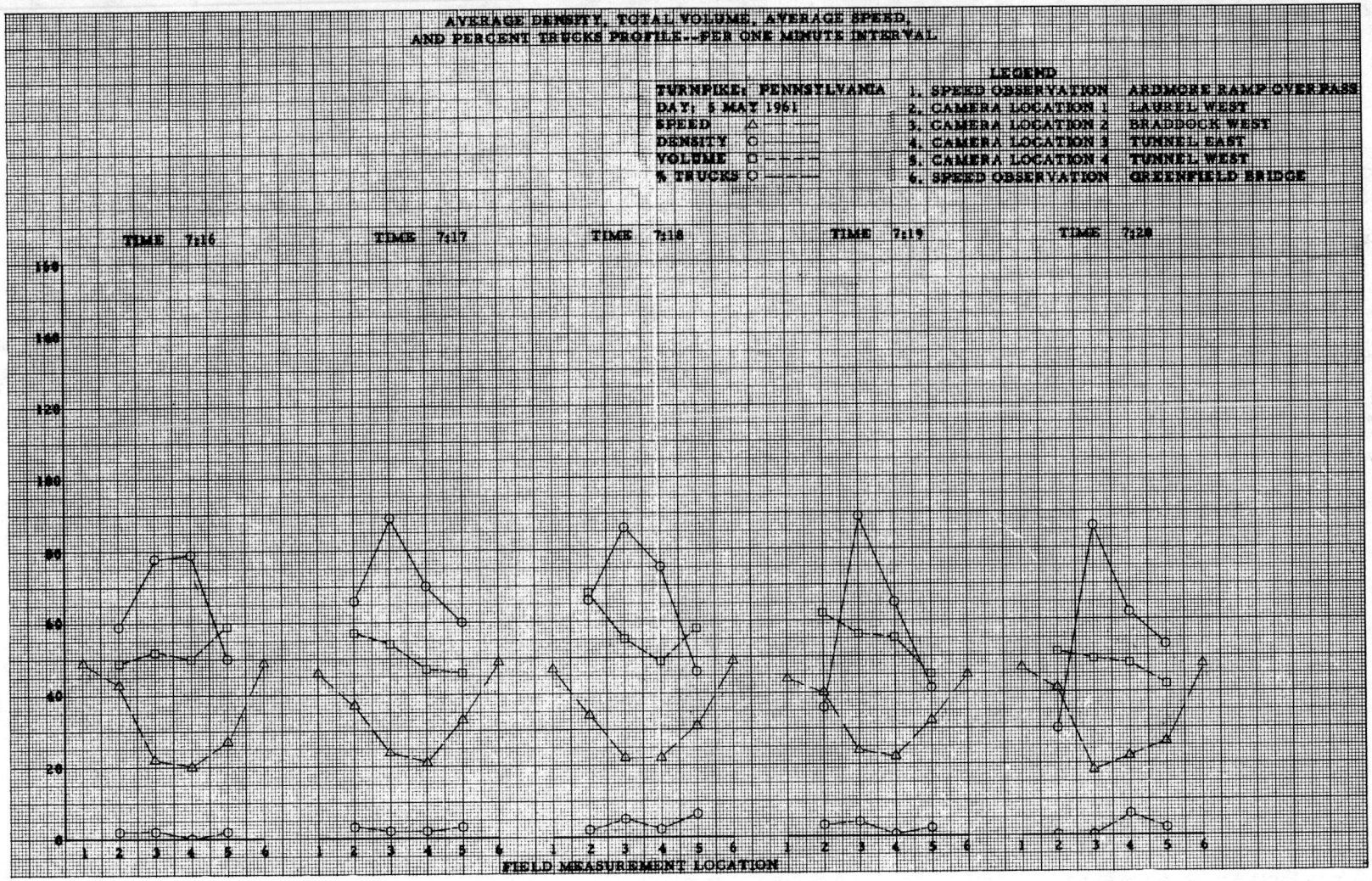


Figure 4. Sample of speed-volume-density distance profiles.

Speed-Volume-Density Interrelationships

Speed-volume, volume-density, and speed-density relationships were investigated to determine (a) the combination of speed and density when volume was maximum; (b) the effect of location (upstream of, at, or downstream from critical controlling point) on the relationships; and (c) if the two study days gave similar results.

The speed-volume relationships for each of the four camera positions and for the two study days were determined and are summarized in Figure 5. Each plotted point represented 1 min of observations and there were 120 points on each graph. The results obtained from the two days are quite similar for each camera position. The curves attempt to represent the enclosure or limits of the speed-volume relationships. The left portion of the figure shows enclosure curves or limits, and on the right side of the figure shows average curves. The diagonal lines sloping upward to the right are average density lines with the steeper slopes representing the lower density levels and the flatter slopes representing the higher density levels. Maximum volumes of 65 vehicles per min occurred at speeds of 25 to 35 mph and densities of 60 to 80 vehicles per mi. The speed-volume curves for Laurel West and Braddock West are quite similar and are typical for locations upstream from a congestion point. The curve for the Tunnel East location is 5 to 10 mph lower than the two curves farther upstream where the study section is not congested (lane densities less than 60 vehicles per mi), which indicates the influence of the tunnel even under light to moderate traffic loads. The curve for Tunnel West is typical for locations just downstream from a congestion point inasmuch as the lower portion of the curve does not slope down and to the left. This is significant because it implies that the congestion point or bottleneck is between Tunnel East and Tunnel West locations.

Volume-density relationships for each of the four camera positions and for the two study days were determined and a summary is given as Figure 6. Each plotted point represents 1 min of observations, and the curve is hand-drawn to indicate the average trend between volume and density. The average curves are shown in the upper diagram, and the enclosure curves are shown in the lower diagram. The radial lines sloping up and to the right indicate average speeds. The same types of conclusions can be drawn from this relationship as were drawn from the speed-volume curves. Maximum volumes occurred at speeds of 25 to 35 mph and at lane densities of 60 to 80 vehicles per mi.

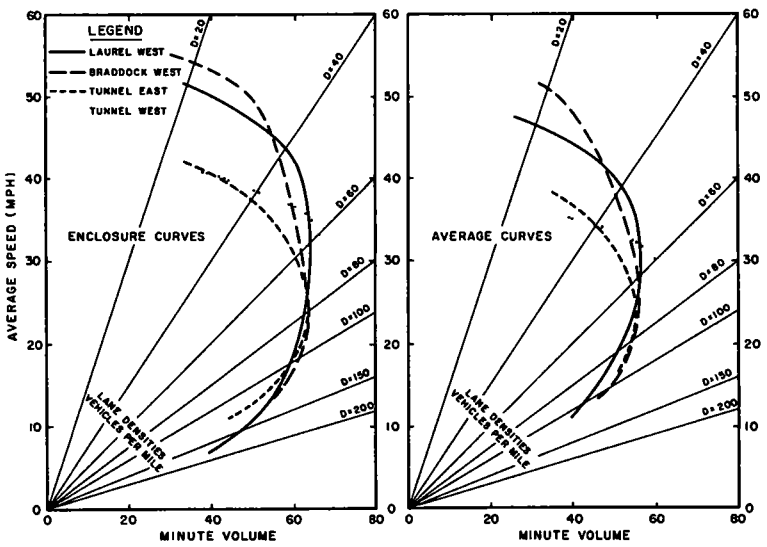


Figure 5. Summary of speed-volume relationships.

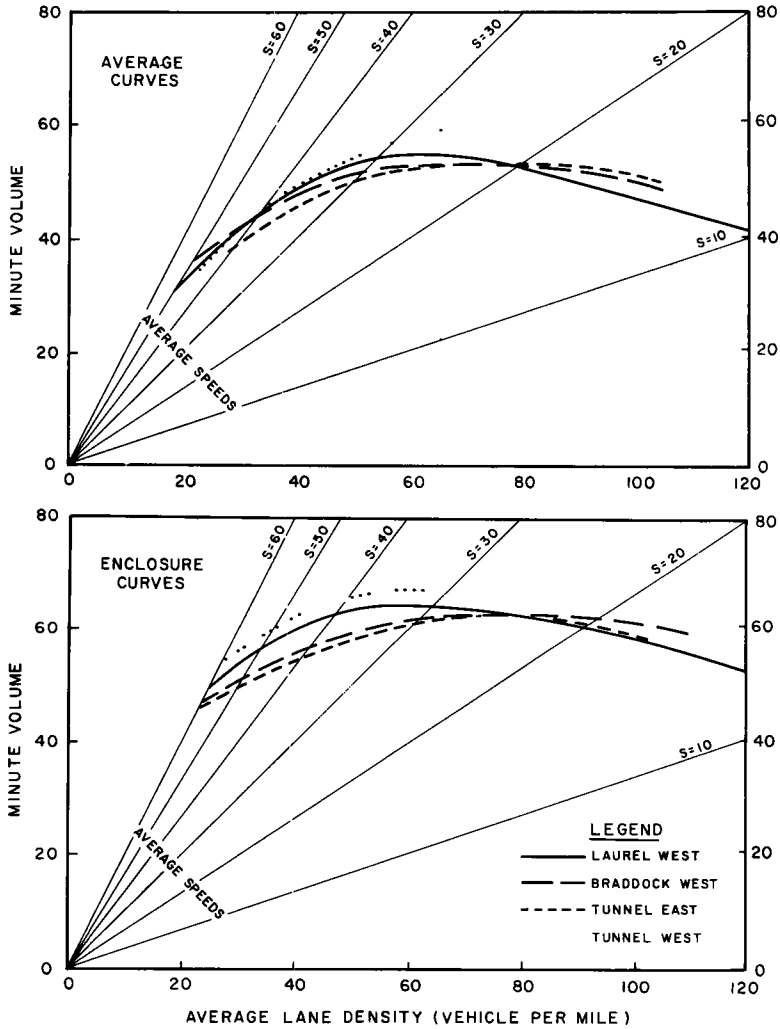


Figure 6. Summary of volume-density relationships.

Speed-density relationships for each of the four camera positions and for the two study days were determined and are shown in Figure 7. Each plotted point represents 1 min of observations, and the curve is hand-drawn to indicate the average trend between speed and density. The average curves are shown in the top diagram and the upper and lower enclosure curves are shown in the graph below. The light lines are indicative of volume rates of 30, 40, 50, 60, and 70 vehicles per min. At the first two locations maximum volume rates occurred at lane densities of 60 to 70 vehicles per mi and speeds of about 30 mph. The maximum volume rate at the entrance to the tunnel occurs at lane densities of about 80 cars per mi and a speed of 20 mph, but the maximum volume rate was not obtained at the tunnel exit.

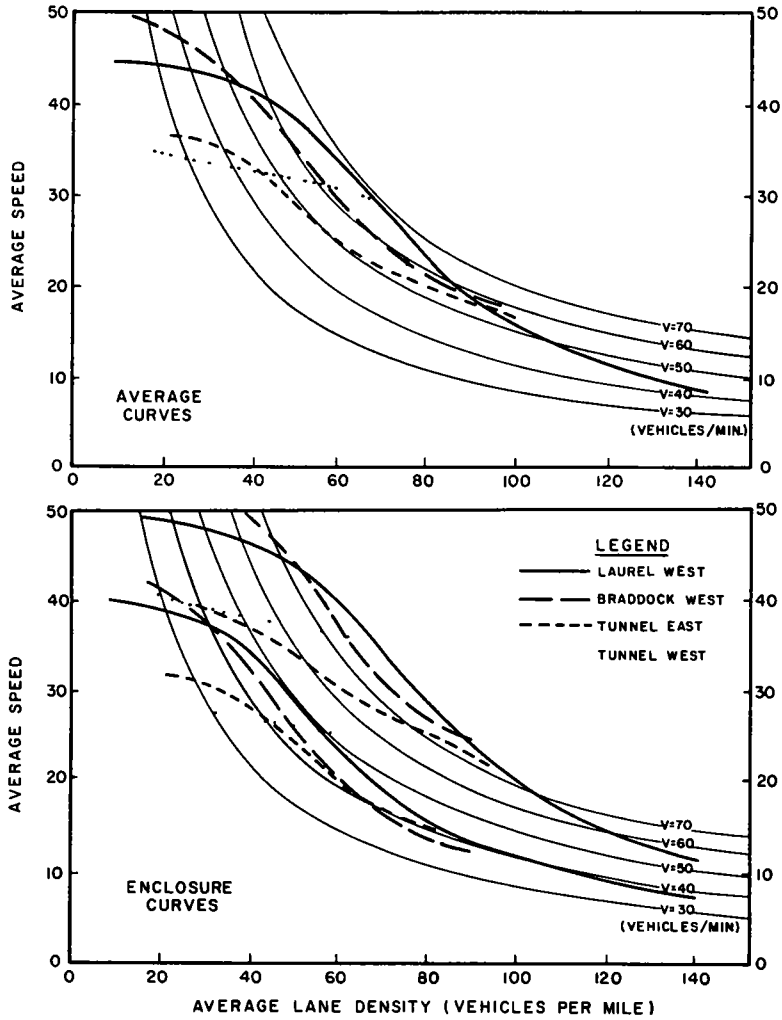


Figure 7. Summary of speed-density relationships.

Comparison of Lane Traffic Characteristics

The analysis procedure followed in the study permitted the comparison of lane traffic characteristics such as volume, speed, and density. As in the analysis presented earlier, the results of each study day and for each of the four camera positions are included.

Lane volume as related to total parkway volume by day and by location were determined. A summary comparing these lane volumes is given in Figure 8. The upper diagram is for the median lane and the lower diagram is for the shoulder lane. The shaded area represents when the indicated lane volume is less than the other lane volume. The median lane at all four locations throughout the morning peak traffic period carried more traffic than the shoulder lane. It appeared that when congestion seriously reduced parkway volume, the shoulder lane carried only 35 to 40 percent of the total volume. As the traffic volume moved from the upstream locations to the downstream locations (as the distance up the grade increased) the shoulder lane carried less and less of its share.

Lane speed related to average parkway speed by day and location was determined. A summary comparing lane speeds is shown in Figure 9. The upper portion of the

diagram is for the median lane and the lower graph depicts the shoulder lane. The shaded areas indicate when the median or the shoulder lane speeds are below the average parkway speed. When parkway speeds were over 38 mph, the median lane speeds at all four locations were greater than the shoulder lane speeds. When parkway speeds were under 20 mph, the median lane speeds at the three locations upstream from the tunnel were less than the shoulder lane speeds. The median lane speeds at the tunnel exit were always 5 to 10 mph greater than the shoulder lane speeds. It appears that the reason for this speed pattern is that drivers approaching the tunnel are willing to travel at lower speeds in the median lane due to high density in order to travel through the tunnel section at the higher median lane speeds, with a net saving in time.

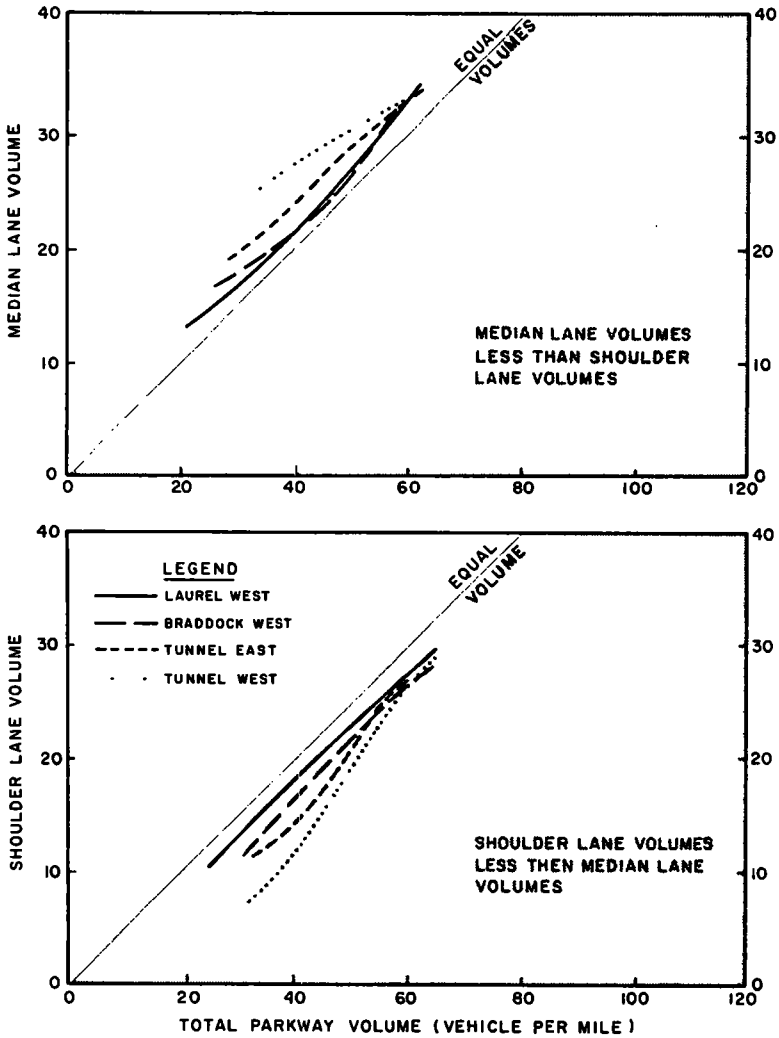


Figure 8. Comparison of lane volumes.

Lane density related to average parkway density by day and location was determined and a summary comparing lane densities is shown in Figure 10. The upper diagram is for the median lane and the lower diagram is for the shoulder lane. The shaded area indicates when the median or shoulder lanes are below the average parkway density. The median lane density is always greater than the shoulder lane density at the three locations upstream from the tunnel, and this is also true for the tunnel exit location for average parkway densities less than 60 vehicles per mi. However, when there is congestion in the tunnel (average parkway densities over 60 vehicles per mi), the shoulder lane has a higher density than the median lane. It would appear that when the tunnel is congested, the shoulder lane traffic does not recover from dense flow as rapidly as the median lane.

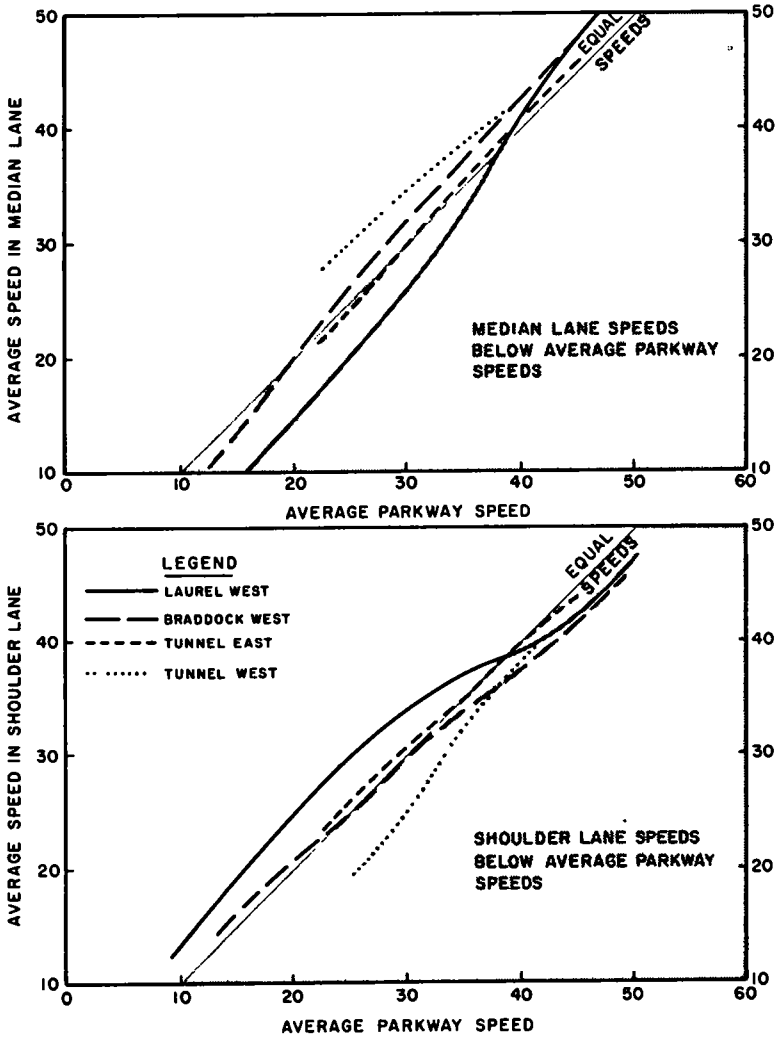


Figure 9. Comparison of lane speeds.

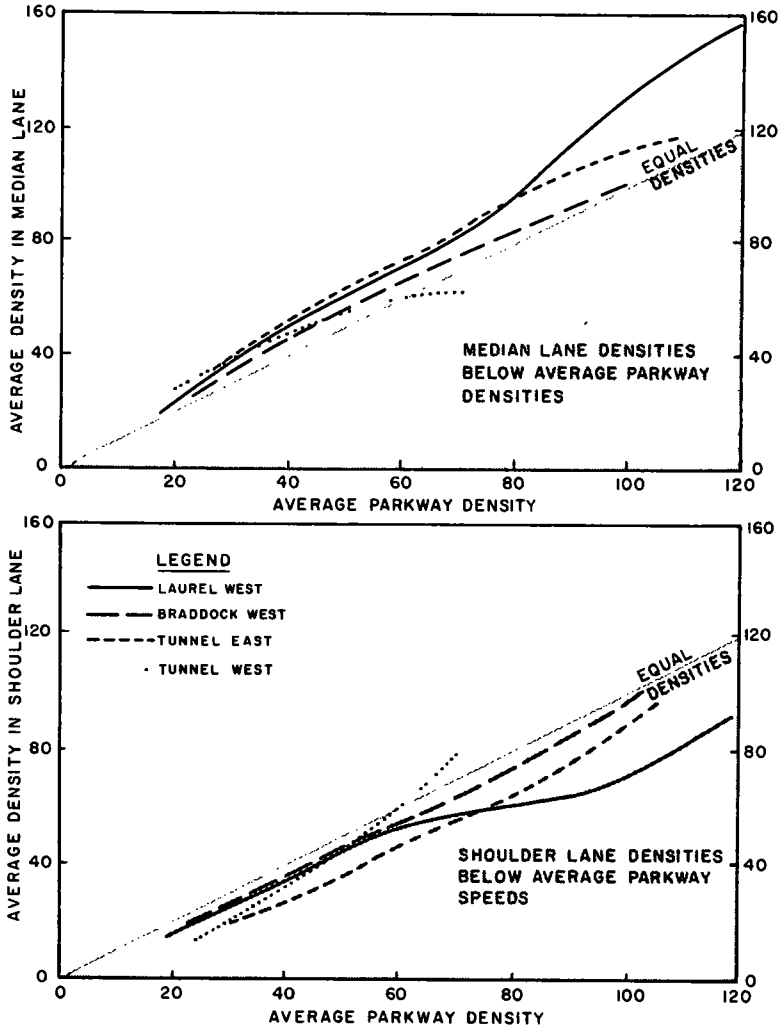


Figure 10. Comparison of lane densities.

Morning Peak Summary of Volumes, Trucks and Speeds

Total volume, truck volume, and average speed by 15-min, 30-min, 1-hr, and 2-hr periods for each camera position, and on an individual lane and parkway basis was ascertained. The total 2-hr volume at the tunnel exit on May 3 and May 5 was 5,991 and 6,008 vehicles respectively. This compares very closely with the total volume recorded at the permanent count station, which was 6,095 and 6,054 vehicles for the same period. Whereas the 7:00 to 8:00 and 8:00 to 9:00 a.m. volumes for the two days ranged from 2,959 to 3,049, the selection of the 1-hr period from 7:30 to 8:30 a.m. resulted in hourly volumes of 3,228 and 3,247 vehicles.

There were a total of 142 vehicles (2.4 percent) on May 3 and 129 vehicles (2.1 percent) on May 5 having six or more tires and these were classified as trucks. The average speeds for the individual camera positions during the morning peak periods for the two days varied from 25 to 33 mph with over-all average speeds on the study section of 28 to 48 mph.

Investigation of Time Headways

The time-lapse photography permitted the measurement of individual time headways and in addition gave the opportunity of identifying vehicles by type and by lane. The films taken from Tunnel West, the camera position at the top of the grade, were analyzed to determine the effect of vehicle type and lane on time headways, and conse-

TABLE 1

TIME HEADWAY DISTRIBUTIONS

Time Headway	TY Type															
	Median Lane		Shoulder Lane		Median Lane		Shoulder Lane		Median Lane		Shoulder Lane		Median Lane		Shoulder Lane	
	Wed.	Fri.	Wed.	Fri	Wed	Fri.	Wed.	Fri	Wed	Fri	Wed	Fri	Wed	Fri	Wed	Fri
1	713	724	378	355	8	7	47	38	2	3	3	5			1	3
2	692	781	598	562	7	7	39	43	2	3	14	17		2	5	3
3	227	213	149	179	1		8	13	4	6	17	18			6	5
4	65	61	45	47	2	1	2	2	4	4	16	12	1		4	1
5	27	19	12	15	1	1			3	2	10	6			2	1
6	13	10	3	9					1		6	11	1			
7	8	7	5	3						1	4	3				
8	3	1	3	1							1					
9	1	2	1	3	1					1	2	1				
10		2		4							1	2				
11	2	1	1	1							3	1				
12		1										1				
13	1		1						1		1					
14	1															
15											4					
16											1					
17																
18									3		1	1				
19		1									2					
20											1	1				
over 20			3								6	13[a]			1	

[a]Maximum gap measured 96 sec.

TABLE 2

AVERAGE TIME HEADWAYS

Vehicle Type	Wednesday						Friday						Wednesday and Friday					
	Median		Shoulder		Both		Median		Shoulder		Both		Median		Shoulder		Both	
	Avg	Freq.	Avg	Freq	Avg	Freq	Avg	Freq.	Avg	Freq	Avg	Freq	Avg	Freq	Avg.	Freq	Avg	Freq
PP	1.93	1,753	2.09	1,199	2.00	2,952	1.90	1,823	2.07	1,179	1 97	3,002	1.92	3,576	2.08	2,378	1 98	5,954
TP	2 35	20	1.64	96	1 76	116	1.88	16	1.78	96	1 79	112	2 14	36	1.70	192	1 78	228
PP+TP	1.94	1,773	2.06	1,295	1.99	3,068	1.90	1,839	2 05	1,275	1 96	3,114	1.92	3,612	2 05	2,570	1 97	6,182
PT	6.1	20	8 98	93	8 47	113	3 45	20	8 99	92	8.00	112	4 78	40	8.94	185	8 20	225
TT	5.0	2	7 21	19	7.0	21	2 00	2	2.54	13	2 47	15	3.50	4	5 31	32	5 11	36
PT+TT	6.0	22	8.68	112	8.24	134	3 32	22	8.19	105	7.35	127	4 66	44	8.40	217	7 77	261
PP+TP+PT+TT	1.99	1,795	2.59	1,407	2.25	3,202	1.92	1,861	2.52	1,380	2.17	3,241	1 95	3,656	2 55	2,787	2 21	6,443

quently is indicative of capacity. Headway distributions by day, lane, and vehicle combinations are shown in Table 1. The average headways and the frequency of headway observations between 7:30 and 8:30 a. m. (the period of greatest congestion) were determined and these values are summarized in Table 2. Vehicle type is identified by two symbols, with the first symbol representing the lead vehicle, and the second symbol representing the following vehicle. The letter P stands for passenger car, and the the letter T stands for truck. For example, PT means that a passenger car is being followed by a truck.

The over-all average time headway for all vehicles was 2.21 sec or a volume rate of 3,260 vehicles per hr. The average time headway for passenger vehicles only was 1.98 sec or a volume rate of 3,640 vehicles per hour. The difference, 380 vehicles per hr, indicates the effect of a relatively small percentage of heavy vehicles in the traffic stream. In comparing time headways between lanes, the passenger car time headways were 1.92 (1,875 vehicles per hr) and 2.08 (1,731 vehicles per hr) in the median and shoulder lanes respectively. The time headway for all vehicles in the median lane under existing conditions is 1.95 sec (1,845 vehicles per hr). In other words, the 22 trucks in the median lane reduce the lane capacity by at least 30 vehicles per hr. In their absence, 52 passenger vehicles could be accommodated.

In order to estimate the increase in capacity that might result if lane changing in the tunnel was permitted, it was assumed that a vehicle during high density flow would change lanes if a 6-sec headway existed (a distance headway between 260 to 350 ft). Using this criteria, the number of 6-sec headways was found to be 132, providing at least this number of lane change opportunities with resultant capacity increase.

Estimation of Traffic Demand

The number of vehicles passing through a bottleneck during congestion is indicative of how many vehicles can get through, but does not indicate how many vehicles would like to pass through the bottleneck. The increase in density upstream from the bottleneck is essentially a measure of the difference between maximum volume and traffic demand. Because volumes and speeds were measured at several upstream locations, density could be calculated and therefore the existing traffic demand estimated. It should be emphasized that the approach presented is an approximation and that this technique permits the estimation of present traffic demand only.

The tabulations required in estimating demand are not contained in this paper but included volume and speed observations at each of five locations and computed average lane densities for each 15-min period; and calculations needed to determine excess densities by 15-min intervals and for four upstream subsections. Because vehicle speeds were essentially unaffected until lane densities approached 40 vehicles per mi, it is reasonable to assume that at this density level the parkway is filled but no vehicles are being stored. When the lane density is in excess of 40 vehicles per mi, the difference between volume and traffic demand can be computed by the equations:

$$S_i = N_i L_i(\overline{D}_i - D_c)$$

and

$$S = \Sigma_i L_i(\overline{D}_i - D_c)$$

in which S_i = number of cars stored in subsection$_i$; S = total number of cars stored; N = number of lanes; L = length of section in miles; $\overline{D}$ = average lane density (vehicles per mile); and D_c = critical lane density (D_c = 40).

The traffic demand for each selected time interval can be computed by the equations:

$$(T.D.)_{T_1} = V_1 + \frac{S_1}{T}$$

$$(T.D.)_{T_2} = V_2 + \frac{S_2 - S_1}{T}$$

$$(T.D.)_{T_3} = V_3 + \frac{S_3 - S_2}{T}$$

etc.

in which

T. D. = traffic demand (vehicles per minute);
V = traffic volume at the bottleneck (vehicles per minute);
S = total number of cars stored; and
T = time interval.

These calculations serve as a basis for determining total vehicles stored, storage rates, and estimated present traffic demand.

Figure 11 shows these results, and can be used to estimate the effect of increased capacity on congestion. The lower boundary of the shaded area represents accumulated traffic volume, the upper boundary of the shaded area accumulated present traffic demand, and the shaded area shows the number of vehicles stored. It can be readily seen from the graph that under existing conditions congestion (vehicles stored) lasts for 1 hr 35 min, and the maximum number of vehicles stored was 220 and occurred at 8:15 a. m.

The effect of increased capacity on congestion is shown by the dashed line. If the volume rate could be increased from 52 to 58 vehicles per min, the duration of congestion would be reduced to 40 min and the maximum number of cars stored would be reduced to 30. The graph also indicates that if the volume rate was increased to 60 vehicles

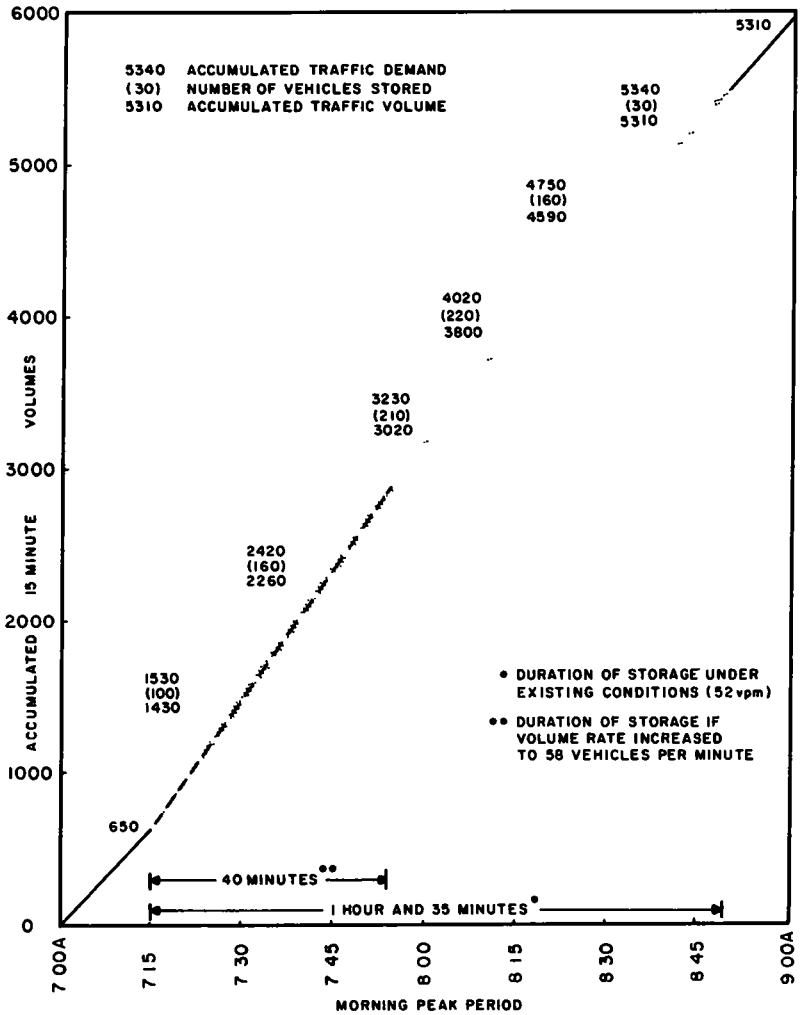


Figure 11. Effect of increased capacity on congestion.

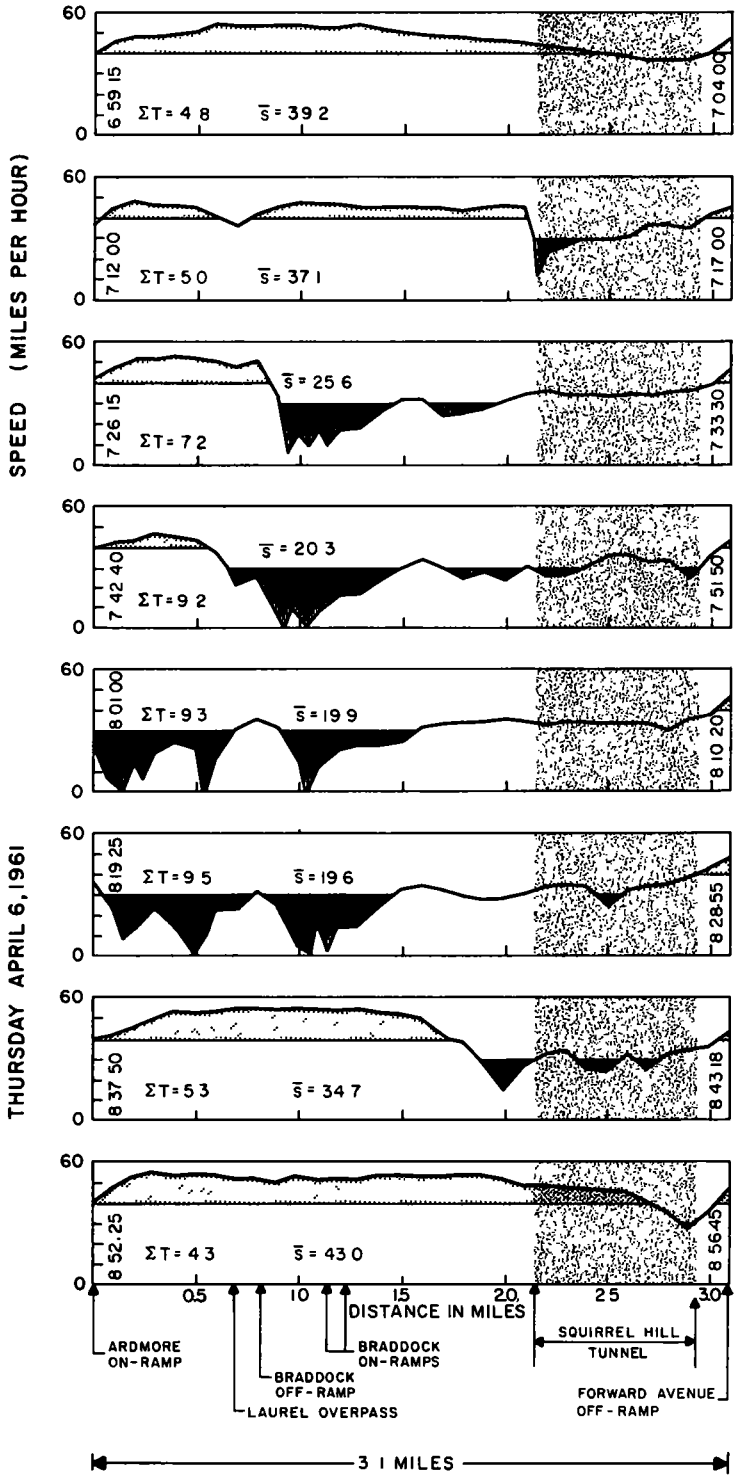
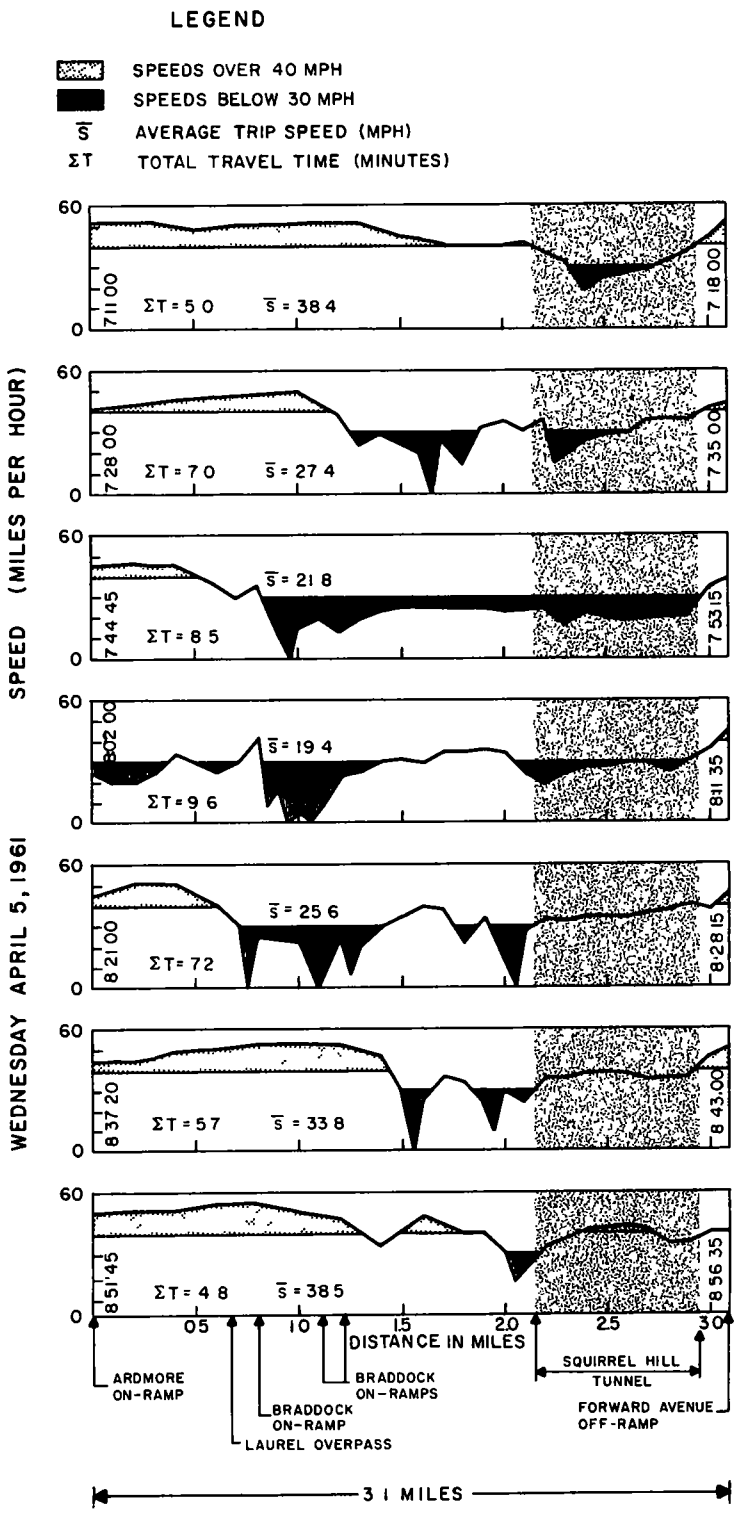


Figure 12, Tra


LEGEND
SPEEDS OVER 40 MPH
SPEEDS BELOW 30 MPH
S̄ AVERAGE TRIP SPEED (MPH)
ΣT TOTAL TRAVEL TIME (MINUTES)
WEDNESDAY APRIL 5, 1961
SPEED (MILES PER HOUR)
ΣT = 5 0 S̄ = 38 4
ΣT = 7 0 S̄ = 27 4
S̄ = 21 8 ΣT = 8 5
S̄ = 19 4 ΣT = 9 6
S̄ = 25 6 ΣT = 72
ΣT = 57 S̄ = 33 8
ΣT = 4 8 S̄ = 38 5
DISTANCE IN MILES
ARDMORE ON-RAMP
BRADDOCK ON-RAMP
LAUREL OVERPASS
BRADDOCK ON-RAMPS
SQUIRREL HILL TUNNEL
FORWARD AVENUE OFF-RAMP
3 1 MILES

ed profiles.

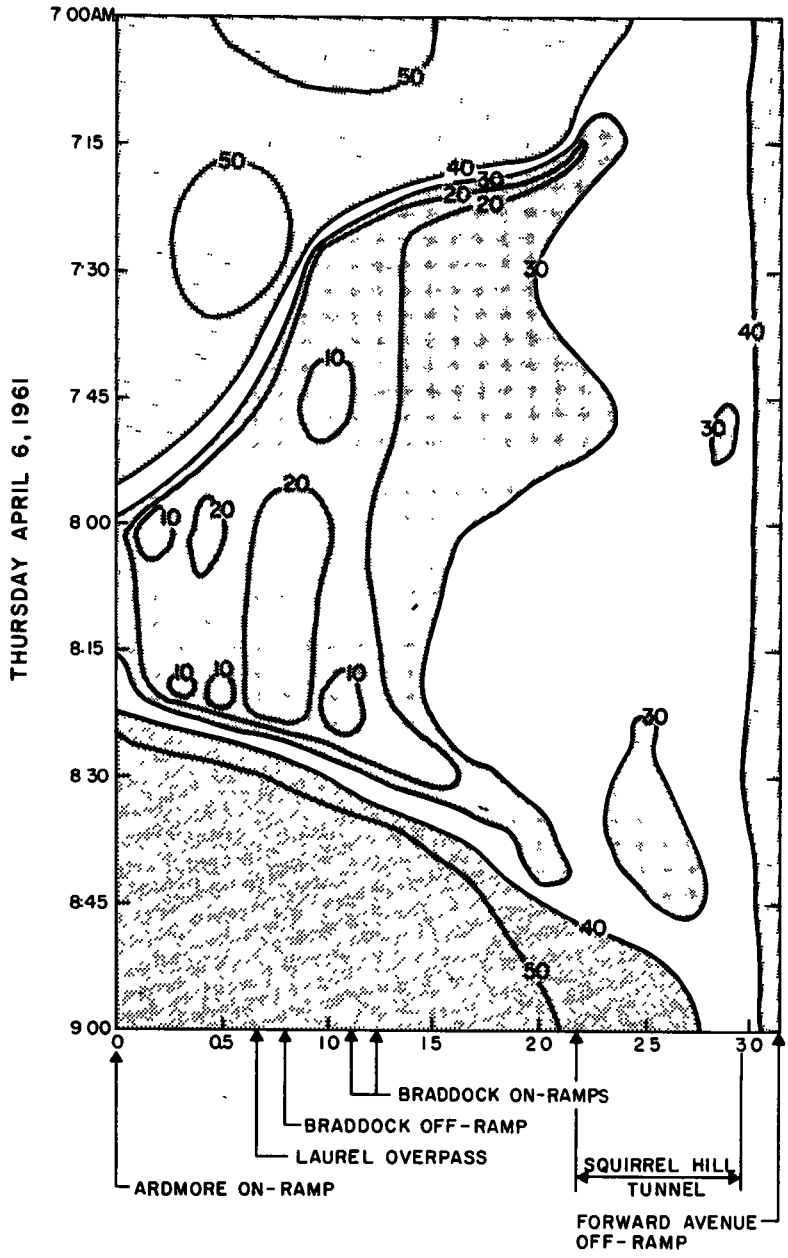
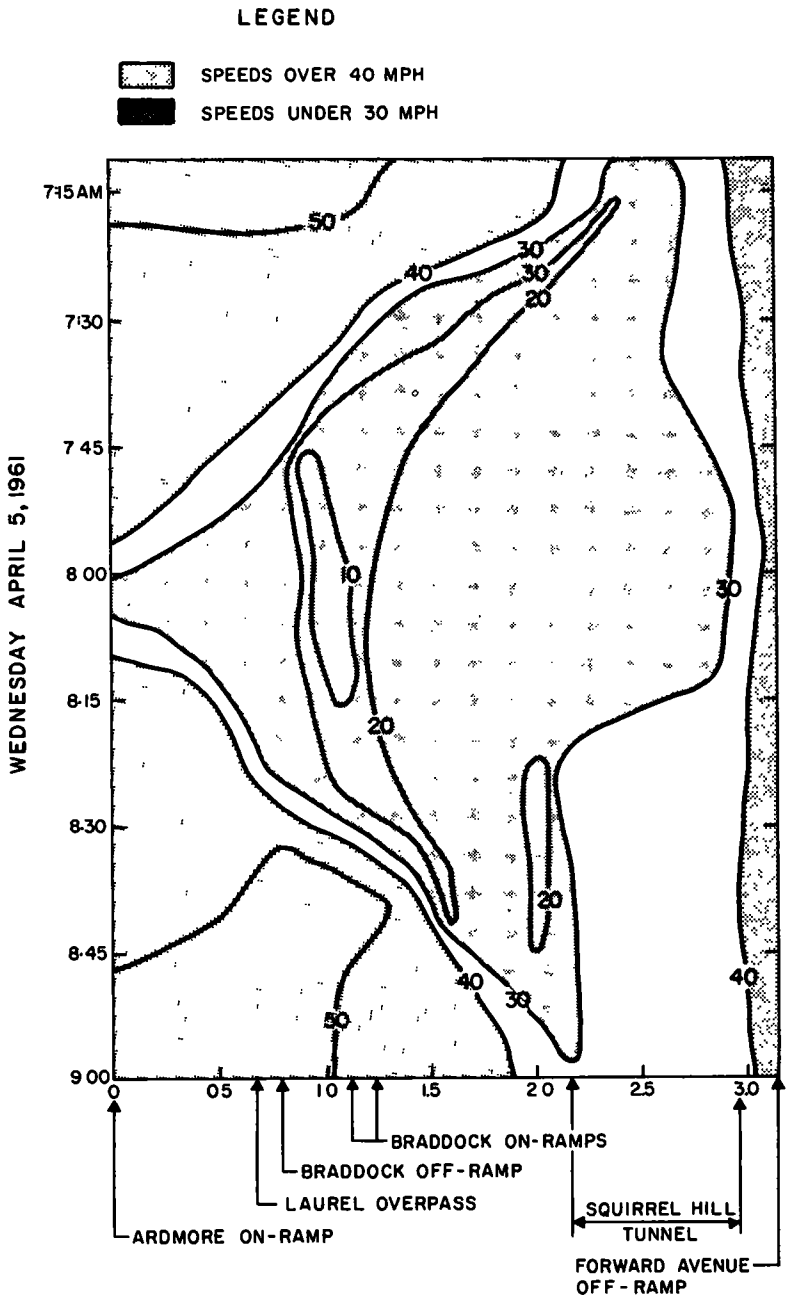


Figure 13. Tra



ed contour maps.

per min no congestion would occur. However, this assumes that the traffic demand is uniform and individual minutes do not exceed 60 vehicles per min. Discussion later in the report will present methods for regulating traffic demand to insure uniformity of flow and better use of the study section.

Travel Time Study

A modified travel time study was conducted on Wednesday and Thursday, April 5 and 6, 1961 on the 3-mi study section from Ardmore Boulevard to the Foreward Avenue off-ramp. In addition to noting the beginning and ending time on each of the 15 test runs, instantaneous speeds were recorded at 0.2-mi intervals when speeds were over 30 mph and at 0.1-mi intervals when speeds were below 30 mph.

The travel speed profiles for the 15 test runs are shown in Figure 12, the beginning and ending time for each test run is indicated as well as total travel time. Speeds over 40 mph were assumed to be satisfactory (no congestion), and speeds below 30 mph were assumed to be unsatisfactory. The light shaded areas indicate portions of the test runs where speeds were satisfactory, and the dark shaded areas indicate portions where congestion was encountered. Average trip speeds varied from 19 to 43 mph (total travel times of 4.3 to 9.6 min).

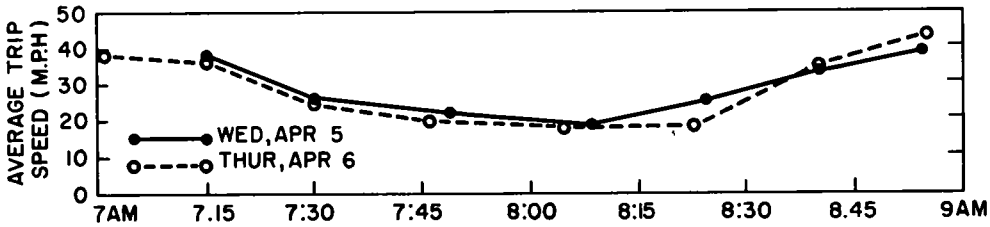
This modified travel time study technique permits a rather intriguing and fact-revealing means of studying congestion. Travel speed contour maps for the two days of study are presented in Figure 13. For each test run where the instantaneous speed changed from one 10-mph group to another (i.e., from 40-49 to 30-39 mph group) the time and location were indicated on this time-distance map. Contours were then drawn connecting points of equal speed. Again speeds over 40 mph were assumed to be satisfactory while speeds below 30 mph were assumed to be indicative of congestion. The lightly shaded area represents periods of time and portions of the study section when speeds were satisfactory, and the darker shaded areas denote periods of time and portions of the study section where congestion existed.

Certain important observations can be made from these contour maps.

1. The travel speed contour maps showing congestion for the two study days are very similar.
2. The congestion on both days originated in the vicinity of the Squirrel Hill Tunnel entrance.
3. The portion of the Penn-Lincoln Parkway downstream from the Squirrel Hill Tunnel was free of congestion throughout the morning peak period and gives evidence of additional available capacity.
4. Congestion began at approximately 7:10 a.m. and ended at about 8:50 a.m. resulting in a congested period of 1 hr 40 min.
5. Stop-and-go traffic conditions extended upstream from the Squirrel Hill Tunnel to east of Ardmore Boulevard (a distance in excess of 2 mi).
6. Shock waves moved upstream at velocities of 4 to 7 mph, while recovering shock waves had velocities of 3 to 6 mph.

The total travel time and the average trip speed was determined for each test run in order to calculate the increased travel time and costs due to congestion. An average trip speed profile for the period 7:00 to 9:00 a.m. for each day is shown in the upper portion of Figure 14, and the graph reveals that the profiles for the two days are quite similar. Knowing the total travel times and calculating the average traffic volume for each of the 15-min periods, the total vehicle hours expended can be computed. The excess travel time due to congestion can be determined by subtracting the total vehicle hours expended if congestion did not occur from the existing vehicle hours expended. An assumed noncongested speed of 40 mph was selected; however, the graph in the lower portion of Figure 14 permits the reader to enter with any assumed noncongested speed between 30 and 50 mph. If the 40-mph value is used, the daily vehicle-hours saved would be 260.

It is difficult to determine the exact value of time to the motorist, but vehicle hourly rates of $1.00 to $2.00 per hr are commonly used. The graph in the lower portion of



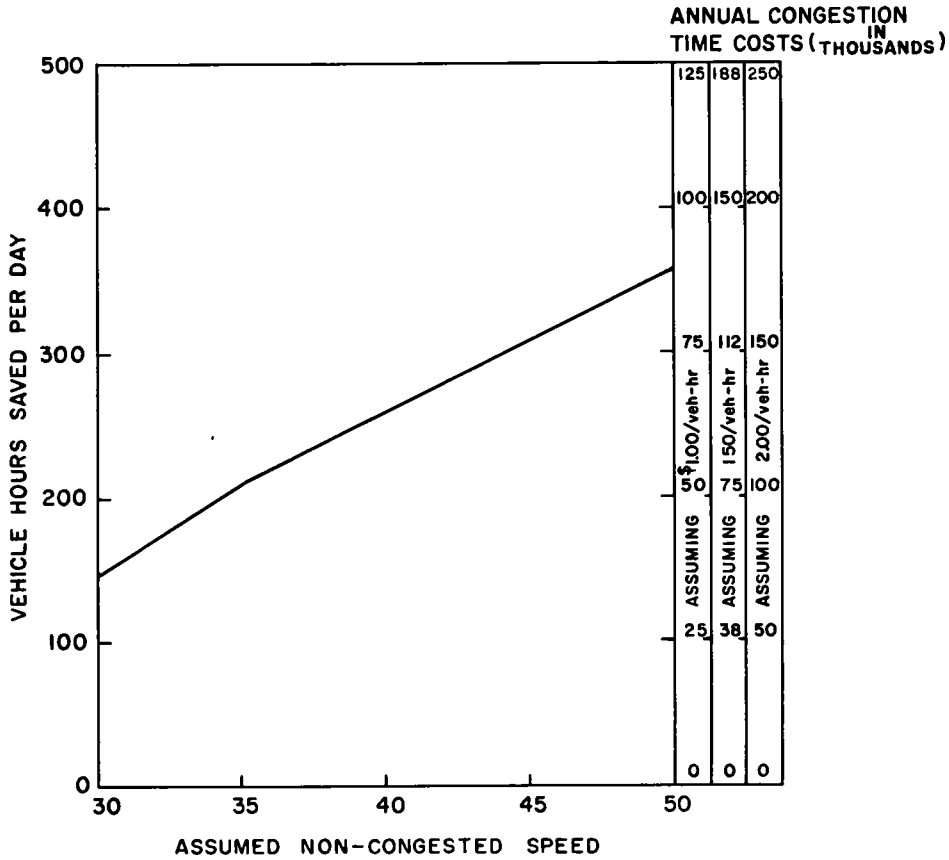


Figure 14. Congestion time costs.

Figure 12 is so constructed that annual congestion time costs (in thousands of dollars) can be read from the graph when hourly rates of $1.00, $1.50, or $2.00 per vehicle-hour selected. For example, the annual congestion time cost is $97,000 when 40-mph noncongested speed is selected and a vehicle hourly rate of $1.50 is used. Future traffic increases will undoubtedly substantially increase the annual congestion time costs.

SUMMARY

Identification of Critical Locations

The results of the speed-volume-density profiles, speed-volume-density relationships, and the travel speed contour maps clearly indicate that the critical location on the study section is at the Squirrel Hill Tunnel. Congestion originates near the tunnel entrance and restricts the capacity of the study section. This restriction to traffic flow

transmits speed and density shock waves upstream as far as Ardmore Boulevard, and also reduces speed throughout the length of the tunnel. The portion of the Penn-Lincoln Parkway from the Squirrel Hill Tunnel toward downtown Pittsburgh is not being fully utilized because of the restriction to traffic flow at the tunnel.

Determination of Causes of Congestion

The restriction to traffic flow near the entrance to the Squirrel Hill Tunnel is caused primarily by the combination of the relatively long grade that increases close to the tunnel, presence of trucks, surges in input volume, and the psychological effect of the tunnel. Other contributing factors include trucks in the median lane and prohibition of lane changing within the tunnel.

Investigation and Evaluation of Means for Improvement

Possible means for improving traffic operations on the study section that were investigated include the following:

1. Permitting passenger car lane changing and truck lane restrictions;
2. Control system plan;
3. Truck use restrictions;
4. Reversible lane operations;
5. Control system plan combined with truck use restrictions and reversible lane operations; and
6. Additional two-lane roadway.

In evaluating the effect of these improvements, the estimated peak hour traffic demand for the period 1961 to 1980 is based on present peak hour demand of 3,600 vehicles per hr with an assumed 3 percent annual increase. A summary of the effects of these improvements are shown in Figure 15 and are described in the following subsections.

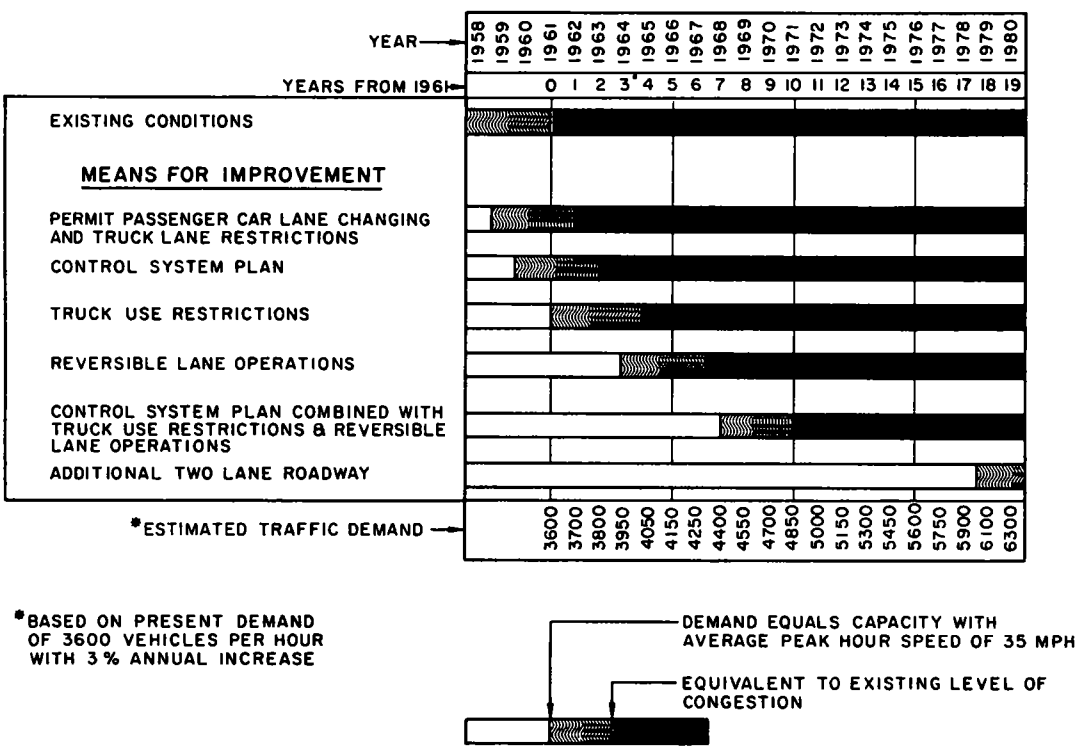


Figure 15. · Estimated effect of improvements.

The transition between the white and gray portions of the bar graphs indicates the year when the peak hour traffic demand is expected to reach the practical capacity of the critical location and therefore would result in an average peak speed of about 35 mph. The transition between the gray and black portions of the bar graphs indicates the year when the present 1961 level of congestion would be expected to recur.

Permitting Passenger Car Lane Changing and Truck Lane Restrictions.—The prohibition of lane changing and the presence of trucks in the median lane slightly reduces the capacity at the critical section. It is estimated (see previous section, "Investigation of Time Headways") that permitting passenger cars to change lanes in the tunnel and the restriction of truck traffic to the shoulder lane will increase the tunnel capacity by 100 to 200 vehicles per hr. Figure 15 indicates that such action would postpone the recurrence of the existing 1961 level of congestion for 1 to 2 years. The immediate effect would be reducing the duration of congestion from 1 hr 40 min to 1 hr, and the congested portion from 2 mi to 1 mi.

Control System Plan.—Volume input rates fluctuate from 2,400 to 3,900 vehicles per hr, and occurrence of an extremely high volume rate prematurely causes a high density condition that results in reduced capacity. One means of preventing this from occurring would be to regulate the arrival rate to a predetermined maximum level, resulting in a smooth steady flow past the tunnel section and increased volume. Experience in the New York Holland Tunnel indicates that the regulation of input has resulted in an increased capacity of 6 percent. Figure 15 indicates that such an increase would postpone the recurrence of the existing 1961 level of congestion for two years. The immediate effect would be reducing the duration of excess demand from 1 hr 40 min to slightly less than 1 hr, and excess vehicles would be stored on ramps or diverted to other routes. Techniques for regulating input volume are discussed later.

Truck Use Restrictions.—The presence of trucks on the upgrade at the tunnel reduces the capacity by 380 vehicles per hr. Figure 15 shows that truck use restrictions would essentially eliminate congestion during 1961 and postpone the recurrence of the existing 1961 level of congestion for four years.

Reversible Lane Operations.—Reversing the flow on the eastbound median lane between Edgewood Avenue and the Greenfield Bridge would increase the westbound capacity by 900 vehicles per hr. Figure 15 shows that such action would result in congestion-free operations for three years, postpone the recurrence of the existing 1961 level of congestion for seven years.

However, restricting the present eastbound traffic flow to a single lane would result in 1-hr duration of congestion and an economic time loss of approximately one-third of the present westbound amount. One means of temporarily eliminating this congestion would be to close the Beechwood Boulevard on-ramp during the morning peak period. (This ramp is now closed during the afternoon peak traffic flow because of its design and proximity to the Beechwood Boulevard off-ramp.) With the reversible lane operations and with the Beechwood Boulevard on-ramp closed, no appreciable eastbound congestion would occur for three years.

Control System Plan Combined with Truck Use Restrictions and Reversible Lane Operations.—The maximum capacity obtainable without constructing additional roadway would be to install an over-all traffic control system that would incorporate truck use restrictions and reversible lane operations. Figure 15 shows that such action would result in congestion-free operations for seven years and postpone the recurrence of the existing 1961 level of congestion for ten years.

A schematic diagram of such a parkway control system is presented in Figure 16. The control system would consist of (a) measurement, (b) decision, and (c) control. Continuous measurements of volume, speed, and density would be obtained from sensors located at the tunnel, and in advance of the Ardmore Boulevard and Braddock Avenue on-ramps. These measurements would be sent to a central computer location for computation, data collection, and control decision. If operations were satisfactory, advance speed and lane use information would be conveyed to the drivers. If operations were unsatisfactory, control decisions could be made to restrict trucks, meter or close ramps, reverse lanes, alert responsible agencies, and convey speed and lane use information to the drivers. The recording of operations and controls would permit the

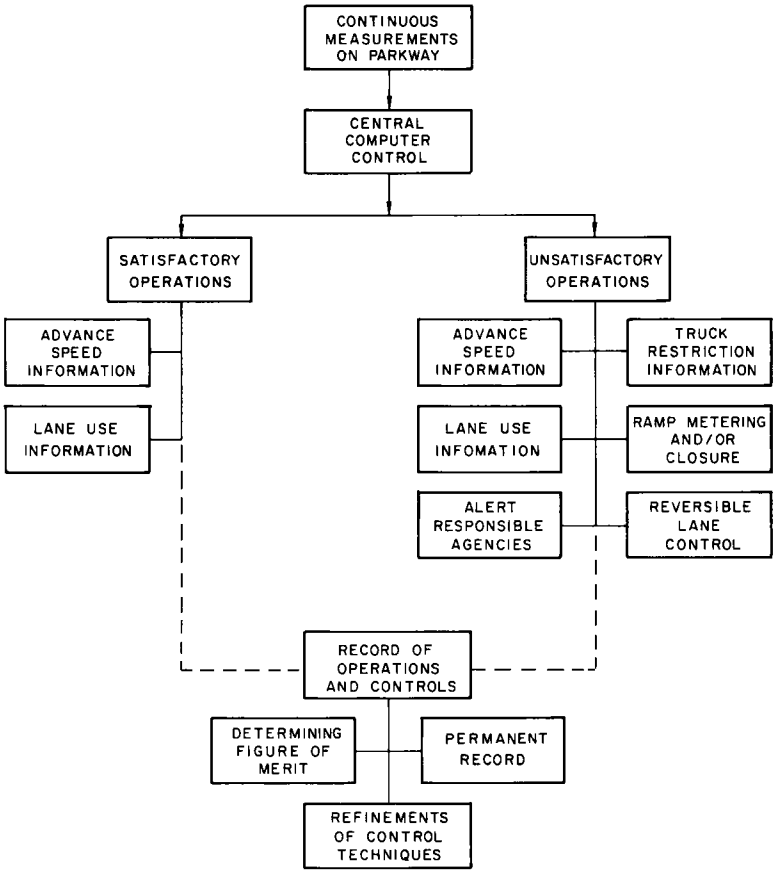


Figure 16. Schematic diagram of parkway control system.

refinement of control techniques, determine the figure of merit, and provide the permanent record of quantity and quality of flow.

Additional Two-Lane Roadway. — The construction of an additional two-lane roadway would increase practical capacity by about 3,000 vehicles per hr. Figure 15 indicates that such action would result in congestion-free operations until 1978. This additional two-lane roadway would not only provide the needed capacity for future westbound traffic, but by reversing the operations during the afternoon peak period, this same roadway could provide the needed capacity for future eastbound traffic.

ACTION TAKEN BY PENNSYLVANIA DEPARTMENT OF HIGHWAYS

The various solutions offered by this study to the immediate problem of congestion at the Squirrel Hill Tunnel were considered by the Pennsylvania Department of Highways at an early October meeting and decisions made based on the forecast of relief to be expected, cost of the time necessary for execution, and political and other considerations. The short-term plan chosen was the lane reversal operation to provide three inbound lanes through the Squirrel Hill Tunnels during the morning peak hours. The truck ban, although easiest and least expensive to put into effect, was rejected due to the lack of suitable routes through the City of Pittsburgh. Longer-range projects include the traffic metering proposal which is now under study by Thompson Ramo Woolridge and the ultimate provision of added capacity through roadway or tunnel construction.

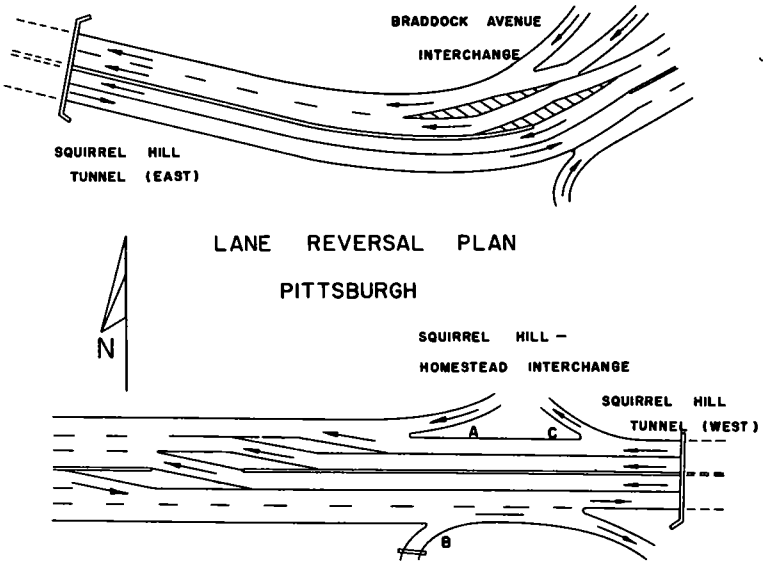


Figure 17. Lane reversal plan used.

Lane Reversal Plan

Due to the impending cold weather and constant public pressure, immediate relief through the lane reversal plan was scheduled for initiation on November 1, 1961, before the first snowfall. Despite some rather caustic comments earlier, the newspapers gave good advance publicity to the project, including some sketches showing what was planned. Guide and control signs were installed where possible and additional portable signs located. Rubber traffic cone placement was planned by using paint spots on the pavement—over 320 cones were to be used. Two 300-ft sections of median were removed and crossovers constructed by Department forces. Figure 17 shows the general area involved and the points chosen for the median breaks—the first at the Braddock Avenue Interchange where between 700 and 800 vehicles per hr entered the Parkway, and the other, west of the Tunnel where the Parkway widened to three lanes westbound. With this heavy an entry volume and to reduce delay and confusion, it was decided that no choice of path could be given to any motorist once he had entered the reversal area. The shaded area on the sketch shows the first phase of cone placement, clearing the lane to be reversed and providing for dispersal at the west end. Placement sequence is carefully planned to reduce hazard to workmen and delay to the public. This operation is usually completed shortly before 6:00 a. m. and takes the two crews about 45 min. Cone placement (cross-hatched area) on the east end at approximately 7:00 a. m. started the three lane operation somewhat in advance of the peak arrival time. (This requires approximately 8 min more for the east crew of five men). Ramp B in the Squirrel Hill-Homestead Interchange contributed about 300 vehicles per hr to the eastbound flow at a critical point very close to where this traffic is reduced to a single lane. To eliminate this confusion and the resultant loss of capacity as well as to lower the demand on the Tunnel, this ramp was closed from 6:00 to 9:00 a. m. (It has been closed during the afternoon rush period for several years.) The lane reversal is discontinued at 8:45 now and within 20 min, two lanes are available to eastbound movement with the westbound flow back in its usual path. Ramp B is opened as soon as these two lanes are again available. The final clean-up of the dispersal pattern west of the tunnel takes a little longer, but all is back to normal by 9:30 a. m.

Operational Experience

The first days of the experiment were free from rain or snow, and almost complete

success was realized in eliminating delay to inbound traffic. Outbound flow, reduced to one lane, experienced some delay as expected, but as time passed, some vehicles used other routes and the "novelty effect" wore off resulting in very little congestion on most days. Other problems included the following:

1. Ramp B closing time. A study of the variation in traffic flow during the period before maximum movement eastbound showed that Ramp B could remain open until 6:30 a.m. and could reopen at 9:00 a.m. without causing congestion. This accommodated a number of rather vocal area residents and aided the public relations on the whole project.
2. Congestion on Ramp A. With the dispersal pattern at the west end, approximately 1,200 vehicles per hr from the Squirrel Hill area were forced to merge into the shoulder lane of the Parkway where almost 1,000 vehicles were traveling. Once again, voluntary rerouting of ramp traffic as well as decreased use of the shoulder lane has almost eliminated this delay.
3. Tunnel ventilation. The design of the tunnel ventilation made use of the motion of vehicles in the tubes to assist in air movement. The introduction of two-way traffic in the south tube eliminated this aid and the carbon monoxide content of the air rose almost to the critical danger level. The same problem had been faced in the other tube during periods of congestion. It was solved by operating all fans at maximum speed for about 30 min before the traffic flow was reversed, which greatly reduced the residual carbon monoxide level and prevented the dangerous accumulation during the 2-hr period.
4. Speed limits were increased somewhat as drivers became experienced with the new operation. Trucks were also restricted to shoulder lanes only on both approaches to the tunnel, reducing long gaps and loss of capacity.

Throughout this period, the local newspapers gave the operation good coverage and generally favorable comment. The only complaint received concerning the inbound improvement came from a man whose employer used the Parkway. He had been accustomed to arriving a few minutes late each day, knowing his superior would be later, but no more; the operation had spoiled his fun.

When the new pattern of traffic flow had settled down, estimates showed that, with essentially no delay through the tunnel, a savings of up to 10 min was being given to the westbound movement, with a benefit in time and gasoline saving to motorists which showed a cost-benefit ratio of approximately 3 to 1. During the first several weeks, traffic was attracted to the free-moving Parkway and volumes increased during the 2-hr peak period by approximately 6.5 percent. The pattern of inbound motorists was also changed in that the hour from 7:00 to 8:00 a.m. showed an increase of 15.0 percent in volume, and the 8:00 to 9:00 a.m. period actually decreased by 2.0 percent (no appreciable change from 6:00 to 7:00 a.m.). The new pattern of movement handled the additional load without measureable delay. Volume comparisons show a generally higher use of the Penn-Lincoln Parkway during 1961-62 than during similar periods over the past few winters.

Counts show that, from 7:00 to 8:00 a.m., the reversible lane was carrying about 1,300 vehicles per hr and the median lane through the north tube carried about 1,200 per hr. The shoulder lane on the north, which still contains the heavy trucks, remained lowest with about 900 vehicles per hr (a total of 3,400 vehicles per hr). The single eastbound lane has carried a maximum volume of 1,613 during the same hour, but usually averages about 1,500 vehicles, a decrease of 500 over the former two-lane volume. During the summer of 1962, it is expected that the traffic demand will at least reach the 3,700 vehicles per hr assumed by the consultant and that this flow will be handled without appreciable delay by the lane reversal plan.

To date, no serious accidents have occurred during the lane reversal period, although this is the first time a tunnel within the metropolitan area has been used for two-way traffic. Minor accidents and vehicle break-downs have been handled by the standard emergency procedures. It is expected that accidents will be reduced on the approach to the tunnel as the start-stop type of operation is no longer required. During the winter months, the liberal use of salt as well as the usual plowing activities has aided in safe and convenient use of the Parkway in the unusual manner.

Future Plans

Now that all concerned are sure of the workability of the lane reversal plan, there remains the problem of a permanent method of operation to replace the large labor force employed. Lane control signals, designed as a part of a traffic metering system, may replace some of the cones now used but the terminal treatment is still under study, as a physical barrier is considered mandatory for a positive diversion of a lane of traffic. Experience gained in other parts of the country will be of great value in solving this control problem.

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