# Some Characteristics of Peak Period Traffic

RICHARD R. CARLL and WOLFGANG S. HOMBURGER, respectively, Assistant Research Economist, and Assistant Research Engineer, Institute of Transportation and Traffic Engineering, University of California, Berkeley

•TODAY serious or incipient congestion can be found on the freeways of any large metropolitan area, and the impression is growing that new urban freeways invariably become clogged with vehicles during peak hours within a few years of their completion. Experience of this sort has tended to breed skepticism among planners, and even highway administrators, about the ability of urban highway expansion to stay abreast of the automobile flood, except by unduly large investments of public funds in roads. One cause of this hesitation about highway improvement is the difficulty of predicting how long an urban freeway can provide effective service to traffic before it is snarled by peak-hour volumes.

The study described in this paper concerns the type of situation where (a) an urban highway route has been congested at peak periods for many years, (b) a substantial addition to road capacity is soon to be made, (c) a restraining limit on traffic growth will thus be removed, and (d) the change can be expected to alter peak-period traffic flow rates. Traffic surveys have been instituted on three important travel arteries in the San Francisco Bay area where notable highway improvements will soon be completed so that it will be possible to identify the time pattern of traffic flows before and after the new highway capacity is added. The surveys are being taken often enough to show trends over time. The findings of the Institute of Transportation and Traffic Engineering will not be available for two or three years, but it was thought it worthwhile to report some of the information collected about peak-period traffic.

The main object in this inquiry will be to determine how the highway improvements will affect the capacity standards used in the course of planning for the urban peak demand. Specifically, it refers to the designation of a "design hour volume" (DHV) to show the future road capacity required along a route, the expression of DHV as a function of total road usage in the familiar formula DHV = ADT x K/100 x D/100, and the concept of "practical capacity," which is based on an "acceptable" vehicle flow rate for a given amount of highway space. Although planning judgment is inherent in all of these values, they tend to be treated somewhat as the result of measurement and prediction; thus, the K-value chosen to designate the future DHV for a highway project is often taken from the existing percentage relationship of peak hour to total daily traffic.

Growing traffic congestion has the effect of lowering the peak percentage values measurable from present traffic flows. If roads were available in such plentiful supply that the rigors of the rush hour played no part in drivers' decisions, a curve depicting the rate of traffic flow over the peak period would probably resemble a mountain peak having a pointed summit, whose altitude would be the size of the peak demand. However, the typical traffic profile for the crowded urban arterial highway in the late afternoon of a weekday has more the appearance of a mesa than a mountain—a mesa with a nearly flat plateau at its maximum height, whose altitude is limited by the capacity of the road to move vehicles. As the peak is flattened, it spreads; and the more potential demand there is during the maximum time period, the wider the spread is likely to be. The spreading of the peak reduces the percentage of total traffic occurring in the maximum unit of time. Congestion both induces and forces drivers to adjust their time and place of travel, and it is reasonable to expect that the relief of congestion would produce changes in the opposite direction.

So far, there has been little specific study of changes in the urban traffic pattern as the result of providing space for vehicles where none before was available. The inquiry intends to record the changes as they occur, particularly in the peak percentage relationship which forms the factual basis of the urban K-value. Presently, it has become possible to describe the peak travel situation before the improvements are completed.

## STUDY LOCATIONS

Three sites in the San Francisco-Oakland Bay Area were selected for this project (Fig. 1). They have in common the following characteristics:

1. The facilities themselves are access controlled by virtue of physical circumstances (a bridge, a tube, a tunnel). Traffic streams do not merge, diverge, or cross within the facilities, except for normal lane changing maneuvers. (Even these do not occur in the two-lane facility being studied.) Traffic is not interrupted by control devices, except on the lower deck of the Bay Bridge, where there is a traffic signal—soon to be eliminated. However, the facilities fail to meet freeway standards as regards provision of shoulders, widths of lanes and, in two cases, separation of opposing traffic streams.
2. The facilities were all constructed before World War II, and have remained substantially unchanged since their opening. At all sites, major construction projects are now underway to increase capacity.
3. The facilities have suffered from peak-hour congestion (as shown by reduced speeds, formation of queues, limitation on drivers' ability to maneuver) for at least ten years, but they have sufficient capacity to handle normal off-peak traffic flows at fairly acceptable standards of service.

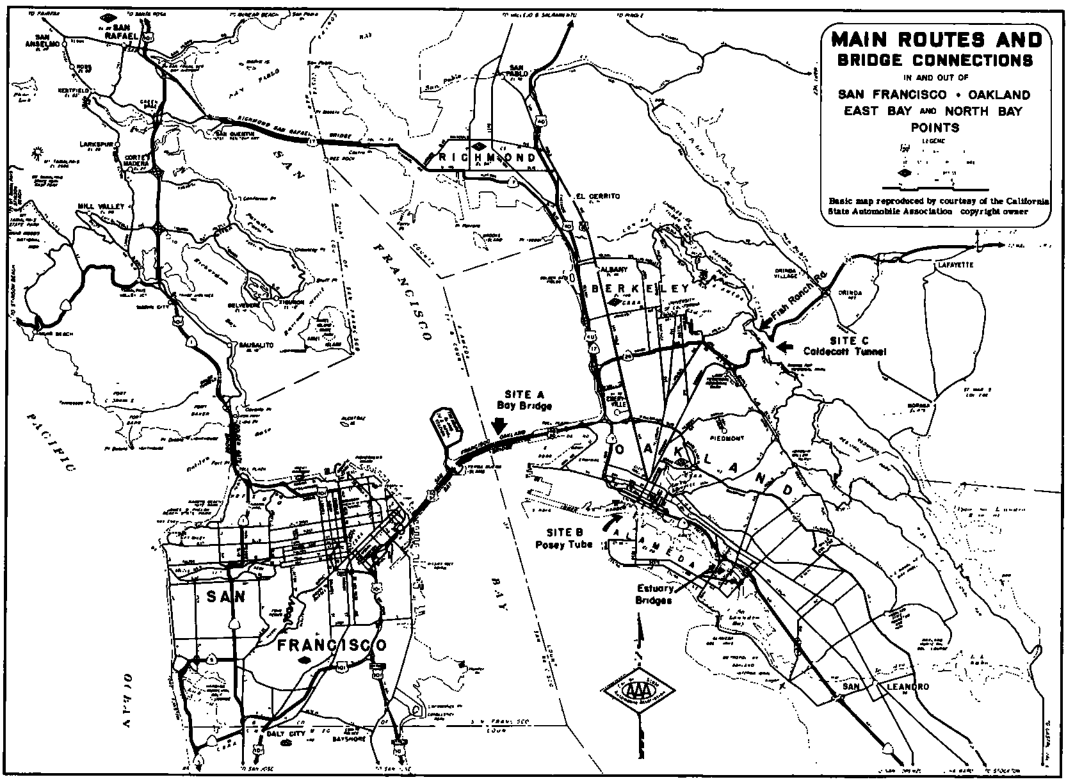


Figure 1. Location of study sites.

4. The capacities of the approaches to these facilities are greater than those of the facilities themselves for at least one direction in each case, permitting the possible capacity of each facility to be determined for at least one direction.

Site A—San Francisco-Oakland Bay Bridge

The San Francisco-Oakland Bay Bridge is the only vehicular facility connecting the two central cities of the metropolitan area across the Bay. The nearest parallel crossings are 10 mi to the north and 20 mi to the south; hence, alternate routes are available for only a minute proportion of trips using this bridge. It would appear that present traffic conditions on the Bay Bridge have had no significant diversionary effect on traffic movement, and the nearest parallel crossings are not being studied to detect such effects.

The geometric features of the bridge which determine its capacity are given in Table 1. The upper deck is restricted to private automobiles and pickup trucks at all times; commercial vehicles must use the lower deck. During peak periods, the center lane of the lower deck operates in the peak direction only, and passenger cars are permitted to use the lower deck during these hours in the peak direction, giving a total of 5 lanes for all peak traffic in the major direction. At other times, passenger cars are not permitted on the lower deck. (Since completion of this phase of the studies, operating rules for the lower deck have been changed to permit passenger cars at all times.)

TABLE 1

PHYSICAL DATA AFFECTING VEHICULAR CAPACITY

| Item | Site | | | | |
|---|---|---|---|---|---|
| | Bay Bridge[1] | | | Posey Tube | Caldecott Tunnel[2] |
| | Upper Dk | Lower Dk | Total | | |
| Traffic lanes: | | | | | |
| Total | 6 | 3 | 9 | 2 | 4 |
| No. for peak direction of flow | 3 | 2 | 5 | 1 | 2 |
| Widths per lane (ft) | $9^2/_3$ | $10^1/_3$ | - | 11 | 11 |
| Shoulders | None | None | - | None | None |
| Median type | Raised | None | - | Paint | Walls |
| Median width (in.) | 8 | - | - | 10 | - |
| Lateral clearance (ft): | | | | | |
| Outer lane edge to curb | None | None | - | None | None |
| Curb to wall or rail | 1 - 3 | 1 - 3 | - | 4 | 4 |
| Posted speed limit (mph) | 40 | 35 | - | 35 | 45 |
| Maximum grade: | | | | | |
| Amount (%) | 3 up | 3 up | - | 4.5 up | 4 up |
| Direction | To east | To east | - | Both | To east |
| Length (mi) | 1 | 1 | - | $^1/_4$ ea. | $^3/_4$ |

[1]Also, 2.7 percent upgrade for $1^1/_4$ mi west.
[2]Also, long upgrades on both approaches.

The present possible capacity of the bridge in the peak direction appears to be about 7,000 vehicles per hour (7.5 percent dual-tired), as given by the figures in Tables 2 and 3. However, because of the absence of shoulders and median over a distance of about 4.5 mi, traffic flow is drastically curtailed whenever a vehicle stops for any reason (out of gas, breakdown, accidents). Stoppages occur in a random manner, but frequently enough to cause wide fluctuations in flow rates measured.

TABLE 2

VEHICULAR CAPACITY DATA, 1961 WEEKDAY

| Item | Site | | | | |
|---|---|---|---|---|---|
| | Bay Bridge | | | Posey | Caldecott |
| | Upper Dk | Lower Dk | Total | Tube | Tunnel |
| 24-hr vehicular volume, both directions: | 99,765[a] | 17,050[a] | 116,815 | 29,645 | 50,302 |
| AM peak hour: | | | | | |
| Time peak hr starts (AM) | 6:54 | 7:00 | 6:54 | 6:30 | 7:30 |
| Volume in peak direction: | | | | | |
| Vehicles | 4,784 | 1,947 | 6,658 | 1,415 | 3,697 |
| % of 24-hr direc. total | 9.4 | 24.9 | 11.3 | 9.4 | 14.9 |
| Dual-tired vehicles in peak direction (%) | 0 | 20.6 | 5.9 | 2.1 | 2.0 |
| Volume in opposite direc. (vehicles) | 2,618 | 312 | 2,920 | 888 | 1,407 |
| Volume in both directions: | | | | | |
| Vehicles | 7,402 | 2,259 | 9,578 | 2,303 | 5,104 |
| % of 24-hr total for both directions | 7.4 | 13.2 | 8.2 | 7.8 | 10.1 |
| Directional split (%-%) | 65-35 | 86-14 | 70-30 | 61-39 | 72-28 |
| PM peak hour: | | | | | |
| Time peak hour starts (PM) | 4:42 | 4:36 | 4:42 | 4:12 | 4:54 |
| Volume in peak direction: | | | | | |
| Vehicles | 4,294 | 2,630 | 6,905 | 1,322 | 3,281 |
| % of 24-hr direc. total | 8.8 | 28.5 | 11.9 | 9.1 | 12.9 |
| Dual-tired vehicles in peak direction (%) | 0 | 18.6 | 7.5 | 3.5 | 1.7 |
| Volume in opposite direction (vehicles) | 3,512 | 374 | 3,867 | 1,257 | 1,264 |
| Volume in both directions: | | | | | |
| Vehicles | 7,806 | 3,004 | 10,772 | 2,579 | 4,545 |
| % of 24-hr total for both directions | 7.8 | 17.6 | 9.2 | 8.7 | 9.0 |
| Directional split (%-%) | 55-45 | 88-12 | 64-36 | 51-49 | 72-28 |
| Two-Directional Peak hour:[b] | | | | | |
| Time peak hour starts (PM) | | | | 4:18 | 7:12 |
| Volume in both directions: | | | | | |
| Vehicles | | | | 2,595 | 5,163 |
| % of 24-hr total for both directions | | | | 8.8 | 10.3 |
| Directional split (%-%) | | | | 50.2-49.8 | 71-29 |

[a]Approximate figure.

[b]For Bay Bridge, same as PM peak hour.

The bridge is now being reconstructed by removal of train tracks and reconstruction of both decks to provide 5 lanes, 11 ft 7 in. wide, for each direction; opposing traffic will be completely separated, westbound vehicles being on the upper deck and eastbound vehicles on the lower. This will no longer permit the operation of any lanes reversibly, as is the present procedure. Nevertheless, the design engineers have forecast an increase in capacity of from 30 to 35 percent, partly because the effect of stopped vehicles is expected to be much smaller.

TABLE 3

HIGHEST, LOWEST, AND AVERAGE PEAK VOLUMES OBSERVED DURING DIFFERENT COUNTING PERIODS

| Facility | Direc of P F | Length of Counts | No of Obser-vations | Traffic Volume (veh ) | | | Percent of 24-Hr Direc Total | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Highest | Lowest | Average | Highest | Lowest | Average |
| Bay Bridge | Westbound | Peak hour | 14 | 6,833 | 6,378 | 6,600 | 13 6 | 11 5 | 12 3 |
| | | Peak half-hour | 14 | 3,718 | 3,428 | 3,606 | 7 3 | 6 3 | 6 8 |
| | | Peak 6 min | 14 | 791 | 722 | 754 | 1 6 | 1 3 | 1 4 |
| | Eastbound | Peak hour | 15 | 7,115 | 5,673 | 6,625 | 13 5 | 11 3 | 12 5 |
| | | Peak half-hour | 15 | 3,669 | 3,076 | 3,467 | 7 0 | 5 9 | 6.5 |
| | | Peak 6 min | 15 | 793 | 625 | 736 | 1 5 | 1 3 | 1 4 |
| Caldecott Tunnel | Westbound | Peak hour | 4 | 3,894 | 3,439 | 3,725 | 16 3 | 14 4 | 15.5 |
| | | Peak 6 min | 4 | 441 | 375 | 417 | 1 8 | 1 6 | 1 7 |
| | Eastbound | Peak hour | 4 | 3,281 | 2,995 | 3,163 | 13 8 | 12 9 | 13 4 |
| | | Peak 6 min | 4 | 355 | 320 | 342 | 1 5 | 1 4 | 1 5 |
| Posey Tube | Southbound | Peak hour | 4 | 1,555 | 1,391 | 1,446 | 10.3 | 9 4 | 9 9 |
| | | Peak 6 min | 4 | 180 | 157 | 165 | 1 3 | 1 0 | 1 1 |
| | Northbound | Peak hour | 4 | 1,356 | 1,321 | 1,332 | 10 5 | 8 9 | 9 6 |
| | | Peak 6 min | 4 | 190 | 145 | 160 | 1 5 | 1 0 | 1.2 |

## Site B—Posey Tube

The Posey Tube connects downtown Oakland with the western section of the City of Alameda under the "Oakland Estuary." (Alameda is actually an island only accessible by this tube and bridges, and the "estuary" is actually a tidal canal.) The tube provides the best connection from the western part of Alameda, which includes a naval air station, to most of the remaining metropolitan area, including San Francisco. It is also a good route out of other parts of Alameda. The nearest parallel crossings are three bridges located 2.5, 3, and 3.3 mi to the east. These bridges are located closer to the downtown sector of Alameda, but further from Oakland's downtown. On the Oakland side, a freeway parallels the estuary and provides a good connection between all the crossing facilities; on the Alameda side, several major streets provide a somewhat slower connection. Therefore, many trips crossing the estuary are offered a choice of facilities. It is probable that the present congested conditions at the Posey Tube have caused an appreciable diversion to the parallel bridges. Hence, they are also included in the long-range study (but not in this report).

The tube has two lanes with passing prohibited throughout its length. Therefore, it actually operates as two one-lane roadways. Vehicle stoppages are rare, none having occurred during any of the counting periods of this project. When they do occur, traffic flow is cut off entirely in the direction of the stoppage unless special police enter the tube to guide traffic around the halted vehicle.

The south portal of the tube is approached by 3 lanes, which reduce to one lane as the tube is entered. During the evening peak a police officer regulates traffic at this entrance, allowing one lane at a time to enter the tube. The north approach is fed from a four-lane city street. A nearby signalized intersection with a one-way street limits the capacity of this approach, but evidently not below the capacity of the tube itself. In fact, the tube can generally carry a heavier vehicle flow from the north approach southbound than in the opposite direction. Values for maximum traffic flows carried are given in Tables 2 and 3.

A new two-lane tube is being built 500 ft west of the existing tube. When the project is completed, each tube will operate in one direction only, and total capacity is expected to increase at least 100 percent.

## Site C—Caldecott Tunnel

Caldecott Tunnel connects the central part of the San Francisco-Oakland Metropolitan Area with a section of Contra Costa County through the Berkeley Hills. These hills reach an elevation of almost 2,000 ft, and are a barrier to easy vehicular movement. While some roads cross this range of hills, only one of these (Fish Ranch Road) is of sufficiently high standards and close enough to divert a large volume of the traffic which would otherwise use the tunnel. This road is being included in the project, but not discussed here.

Traffic through Caldecott Tunnel during peak hours is largely of the commuter type. The region east of the tunnel is a "bedroom community," many of whose wage-earners work in Oakland, Berkeley, or San Francisco. Table 2 shows traffic at this location has a far heavier inbalance by direction during peak periods than at the other locations.

The tunnel consists of two bores, each two lanes wide, on a continuous 4 percent grade up from west to east. The top of the grade is near the east portal, and both highways approaching the tunnel do so on long uphill grades of 4 to 5 percent. The approach from the west is two lanes wide, that from the east three lanes wide. Fish Ranch Road joins the main highway just east of the east portal. Thus, traffic volumes on the east-approach highway are greater than through the tunnel itself. In the westbound direction this poses no capacity problem, because the extra uphill lane is available; however, there are only two lanes downhill from the tunnel eastbound, and these must carry all tunnel traffic plus the vehicles entering from Fish Ranch Road. The capacity of the tunnel in the eastbound direction is therefore not believed to be the critical one, and volumes measured are believed to be controlled by the merging just beyond the tunnel. In the westbound direction, tunnel capacity probably is the limiting factor.

The Fish Ranch Road alternate route, which joins the main highway at the east portal, diverges northwards on the west side of the hills, and is a possible, though inferior route for traffic originating or terminating in the northern part of the East Bay Area, and, perhaps, to traffic crossing the San Francisco-Oakland Bay Bridge. It is probably little used by traffic to or from Oakland and points south, nor by the majority of traffic to and from the Bay Bridge. The present role of this road as an alternate during periods of congestion can best be seen by noting that the westbound peak hour carries 36 percent of the 24-hr westbound total, and the eastbound peak hour 43 percent of the 24-hr eastbound total. The road sees relatively little use in off-peak periods.

A new bore, also two lanes wide, is being built just north of the existing bores, and the approach highways on both sides are being converted to eight-lane freeways. On completion of these projects, the center bore will be operated reversibly during peak hours, and there will be four lanes in the peak direction on the approaches and through the tunnel. In the direction opposite to the peak movement, traffic will be restricted to two lanes through the tunnel. Traffic capacity in the peak direction should increase about 100 percent.

## FIELD STUDIES

The following studies are being conducted in the field:

1. Total Vehicle Volume Counts.—At all sites and parallel routes deemed to have a diversionary role. At the sites themselves, peak period data are subtotaled every 6 min, other data every hour. At parallel route sites, peak period data are subtotaled at either 6- or 15-min intervals.
   (a) Bay Bridge—Counts are made by electronic machine connected to toll booths recording each transaction.
   (b) Posey Tube—Counts are made by street traffic counters modified to print at 6-min intervals. Detection is by sonic vehicle detectors mounted overhead near one portal. On two of the parallel bridges, permanently installed photoelectric detectors are connected to street traffic counters; at the third bridge road tubes are used.
   (c) Caldecott Tunnel—The same procedure as at Posey Tube is used. On Fish Ranch Road, road tube detectors are employed.

2. Vehicle Classification Counts.—At all sites, but not on parallel routes. These counts are made manually.
   (a) Bay Bridge—Continuous counts are made during peak periods, using 6-min intervals for subtotals. During off-peak periods, 30 min are counted every hour, or data obtained by operating agency are used.
   (b) Posey Tube—During peak periods, approximately 12 min are counted every one-half hour; during off-peak periods, about 24 min are counted every hour.

(c) Caldecott Tunnel—Same procedure as at Posey Tube.

3. Vehicle Occupancy Counts.—At all sites, but not on parallel routes. These counts are made manually.

(a) Bay Bridge—Counts are made at the toll plaza, by sampling three or four lanes at a time. Counting continues about 21 min per $\frac{1}{2}$ hr in peak periods, and about 30 min per $\frac{1}{2}$ hr in off-peak periods. This results in sample sizes of from 20 to 25 percent.

(b) Posey Tube—During peak periods, approximately 12 min are counted everyone-half hour; during off-peak periods, about 24 min are counted every hour.

(c) Caldecott Tunnel—Same time schedule as at Posey Tube. Both lanes are counted simultaneously, although during peak periods some vehicles may be missed.

4. Transit Riding Counts.—These are made at Sites A and B only.

(a) Bay Bridge—The two transit agencies carrying local passengers across the Bay Bridge both use a toll ticket system on which drivers enter the number of passengers carried on each trip. These data are tabulated for a 24-hr period against the time at which each trip is scheduled to pass through the toll gate. (If vehicles are not on schedule, no allowance is made for this fact.) Long distance bus schedules are not included in this tabulation, nor are buses that shuttle passengers between San Francisco and the various long-distance railroad terminals in Oakland.

(b) Posey Tube—Estimates are made of the numbers of passengers on every bus passing through the tube between 6:30 AM and 6:30 PM. In off-peak periods, these estimates are apt to be somewhat rough, because buses then may be traveling at 30 mph past the observer.

(c) Caldecott Tunnel—No transit counts are made at this site, because the speed of buses (up to 50 mph) and the type of equipment used would make counts very inaccurate. Well over one-half the buses passing through Caldecott Tunnel then proceed across the Bay Bridge (and vice versa) without intermediate stops; for this group of buses data are available at the Bay Bridge.

The series of field studies listed is performed at quarterly intervals (January, April, July, October) at the Bay Bridge, and at semi-annual intervals (Spring, Fall) at the other sites.

## ANALYSIS OF PEAK PERIOD TRAFFIC PATTERNS

Basic data in these studies are the 6-min counts of all vehicles passing through the highway bottlenecks during peak periods. The picture of the peak they present before the forthcoming additions to highway capacity is portrayed in this section.

Inspection of the data for Site A, the Bay Bridge, is convincing that by 1961 the reconstruction of the lower deck had progressed to the point where enough of a change had been made in total Bridge capacity to affect the flow patterns. Therefore, the information for the Bridge in the remainder of this paper represents only the counts taken in 1959 and 1960. For the Tunnel and the Tube, the data presented here include all counts completed to date.

## PEAK PERIOD VOLUMES AND PERCENTAGES

Generally, the values given in Table 3 represent the vehicle volumes that occur from the fullest use of the facilities during the entire peak hour; they indicate the maximum ability of the roads to handle traffic flows. This is not quite true for the Bay Bridge during the morning, westbound peak, when some additional cars could be carried on the lower deck in the maximum hour; it is also possible that slightly higher southbound volumes could be recorded for the Posey Tube if the city streets of Oakland permitted a more regular flow of vehicles. Otherwise, the peak situation is such that no additional vehicles could come onto the bridge, the tube or the tunnel in the peak hour without crowding others off.

Despite this fact, there is a certain amount of variation in the maximum volumes which are recorded upon separate days. Table 3 gives the extremes and the average values for each of the facilities, which is a rough way of noting the dispersion of the data. Any dispersion is due mainly to irregularities in the traffic stream caused by vehicle stalls, accidents, climate or driver behavior under highly congested conditions, rather than to differences in the total number of vehicles desiring to use the roads.

The range between the high and the low hourly values was found to be greatest for eastbound Bay Bridge traffic, mainly because of vehicle stalls. The finding has been that delays and accidents on the Bridge during the afternoon peak have caused a considerable fluctuation in the rates of vehicle flow. Because the counts are taken at the toll gates at the east end of the Bridge, there has been no opportunity to measure the effect of similar interferences to traffic during the morning peak, but the impression is that accident delays are not as severe as in the afternoon. About accidents, more will be said later.

Because traffic is at a maximum during the peak, the percentage relationships between peak and total daily traffic are the highest that could be calculated at the present time. Unless road capacity is increased, traffic volumes during the peak cannot rise. Therefore, traffic increases could occur only in off-peak periods, and this would reduce the percentage of total traffic in the peak.

The percentages are highest for the Tunnel and lowest for the Tube. The low values for the Tube reflect the directional factor: in both the morning and the afternoon, there is a peak flow in each direction in the Tube which reaches the full capacity of the facility for a sustained time period. Also, the Tube is located near the heart of the urban complex, and off-peak usage is relatively heavy. By contrast, the peak flow through the Tunnel is primarily composed of traffic coming out of bedroom suburbs in the morning and going home in the afternoon: it is highly one-direction, and the off-peak travel is moderate in size. The percentages for the Bridge show both influences: the Bridge connects the major central cities of the Bay area, but the primary flow is in and out of San Francisco, rather than Oakland, and the length of the Bridge has a restraining effect on off-peak movements.

Traffic volumes and peak percentages for shorter time intervals than the maximum hour have been recorded in order to have a measure of the "peaking" tendencies of the traffic stream. As the traffic flow profile acquires more of the aspect of a "peak," the values for the shorter intervals should rise in relation to the hourly values. If capacity were used so that there was a perfectly even flow of vehicles throughout the period, the volume in each 6-min interval would be precisely 10 percent of the peak-hour volume. However, even when there is a continuous queue of cars waiting to enter a bottleneck, the flow is not entirely smooth. This fact, previously observed by the California Division of Highways (1), is apparent in these studies. Referring to the average vehicle volumes in Table 3, each peak 6-min volume bears the percentage relationship to the peak-hour volume given in Table 4. This variation exists even when capacity is fully utilized.

If the addition to highway capacity along these routes were to cause a greater peaking of traffic, as is expected, the change should increase the peak percentages more for the shorter time intervals than for the maximum hour. This hypothesis will eventually be tested in the course of the investigation.

## Peak Period Flow Profiles

Using the 6-min vehicle counts, an attempt has been made to determine the length of time during the rush hours that each facility is actually utilized to its full physical capacity. The traffic profiles over the total peak period are shown in Figures 2, 3, and 4. The traffic volumes represented by these curves are hourly rates of flow for

6-min intervals; that is, each 6-min volume is multiplied by 10, which converts it into an hourly rate.

The curves are averages of all of the individual days for which peak period vehicle counts were completed. The curves for the Bay Bridge are composed of counts taken between April 1959 and October 1960. Over this time, there was a mild increase in total peak period traffic, resulting in a slight lengthening of period of maximum flow, but the change is not of much significance. In the westbound direction on the Bridge, the curve represents 14 counts, and in the eastbound direction 19 counts. The Caldecott Tunnel curves are an average of 6 counts westbound, 7 counts eastbound, made during 1960 and 1961.

TABLE 4

PERCENTAGE RELATIONSHIP OF 6-MIN VOLUME TO PEAK-HOUR VOLUME

| Test Area | Traffic Flow | Percentage Relat. (%) |
|---|---|---|
| Bay Bridge | West | 11.4 |
| | East | 11.1 |
| Posey Tube | South | 11.4 |
| | North | 12.0 |
| Caldecott Tunnel | West | 11.2 |
| | East | 10.8 |

Figure 3 for the Posey Tube shows the traffic flow in each direction during the morning and afternoon peaks for reasons previously explained. Only 4 days are depicted by each curve (3 days in the southbound AM direction), which accounts for the irregularities in the lines.

The treatment of the traffic movements on the lower deck of the Bridge and on Fish Ranch Road at Caldecott Tunnel must now be explained.

Both the lower deck (at least at the time these counts were taken) and Fish Ranch Road are "inferior" routes to practically all of the passenger car traffic. They would be selected only because traffic congestion on the superior roads induced drivers to choose the less attractive alternative. This is much more true of Fish Ranch Road than the lower deck, but it is probable that enough additional capacity on the upper deck of the Bridge, or at the Tunnel, would divert nearly all of the passenger cars away from the inferior routes.

In Figure 2, the flow of vehicles on the upper deck of the Bridge has been estimated by deducting the lower deck traffic volumes from the totals. This procedure was required because the traffic counter at the toll gates does not distinguish between upper and lower deck vehicles. The lower deck figures were obtained manually, in the course of the vehicle classification counts. Only one classification count is made at each quarterly survey, so that the lower deck flow shown in the figure represents the average of seven days, rather than 14 or 19 days.

In Figure 4, the values for Fish Ranch Road were added to the total volumes for the Tunnel. The estimates for the Road are rough—only two days have been used in the westbound direction, and four days in the eastbound direction.

On each chart the average midday rate of flow has been shown, so that an impression might be gained of the extent that the maximum capacity of the facilities exceeds the normal traffic requirements of the time period between the morning and afternoon peaks.

Bay Bridge AM Peak (Westbound).—If the vehicle flow has the appearance of a peak here, it is because the lower deck was opened to passenger cars during the peak period. When this availability of the lower deck began at 7:00 AM, the volume on the upper deck had almost attained the maximum flow rate of 5,000 vehicles per hour. This flow declined slightly as the uncongested lower deck attracted traffic, then rose as total volume increased. At 8:00 AM, the closing of the lower deck to automobiles coincided with an abrupt increase in the upper deck rate of flow.

Total volume on the Bridge reached a rate of almost 7,500 vehicles per hour on the average. This figure is probably the highest rate of flow possible for the five lanes open to peak traffic in the primary direction.

Bay Bridge PM Peak (Eastbound).—At 4:00 PM, traffic on the upper deck was already at the maximum possible volume and well above the midday rate. (Further investigation showed a sharp rise in traffic beginning around 3:30 PM and continuing until full capacity is reached.) At 4:30 PM, the lower deck was opened to passenger cars, and the increased flow of vehicles arrived at the toll gates some 10 min later. Then there was a sharp increase in volume until the Bridge was operating at full capacity on both decks.

The maximum total rate of flow is only about 6,700 vehicles per hour, compared with 7,500 in the morning peak. On the upper deck alone, the flow averaged about 500 vehicles per hour less than the westbound flow in the morning. This difference reflects the effect of numerous stalls, delays, and accidents that occur on the Bridge. On each individual day, the maximum rate-of-flow usually exceeded 7,000 vehicles per hour for at least a short-time interval, but it was difficult for this rate to be sustained without interruption. Because stalls and other delays are distributed over the whole congested period of the peak, they tend to pull down the general average values for all days for the entire time period.

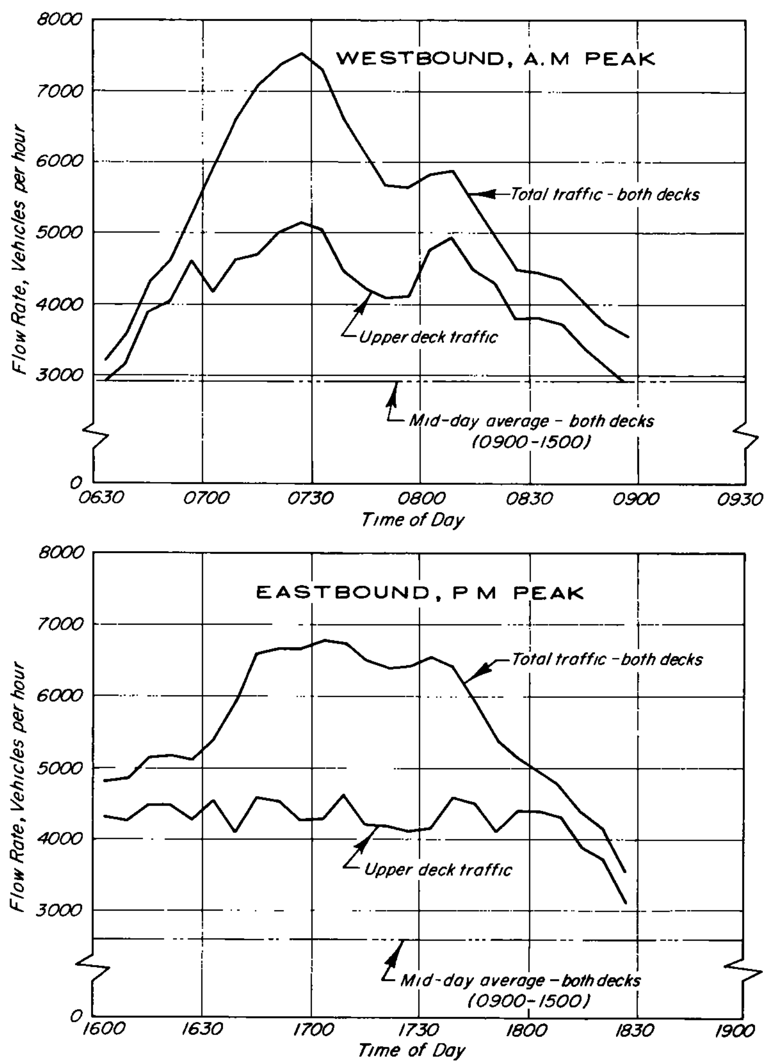


Figure 2. Peak period traffic flow, Bay Bridge.

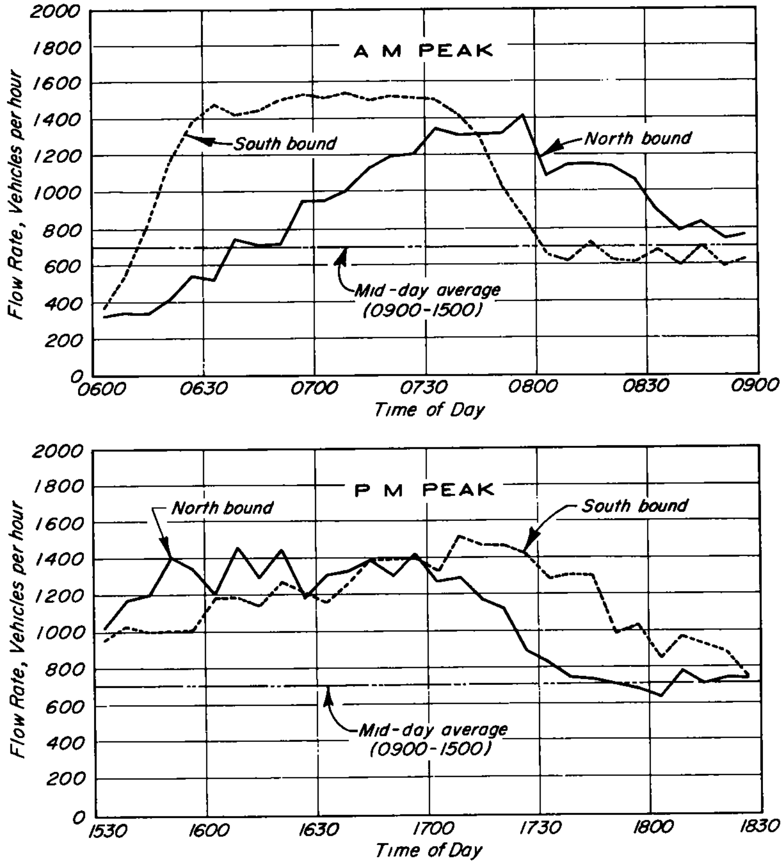


Figure 3. Peak hour traffic flow, Posey Tube.

It might be objected that the inclusion of volume data which are affected by stalls does not give a true picture of the maximum capacity of the Bridge. However, if the probability that accidents will happen is a function of the size of the total flow and the degree of congestion, then the capacity-reducing effect of accidents cannot be disregarded. It is certainly not disregarded by users of the Bridge—stalls of one kind or another are such frequent events that the possibility of being delayed by them undoubtedly influences driver decisions about when and whether to use the Bridge. Accidents tend to lengthen the peak period, as well as reduce the average rate of flow. Because individual delays cannot be foreseen by motorists, a peak accident causes a queuing of vehicles until the removal of the obstruction, then flow continues at a maximum rate beyond the time when it normally declines.

One attempt was made to measure the effect of accidents on Bridge capacity and the time pattern of traffic for the afternoon Bridge peak. Of the 19 days constituting the sample of the eastbound peak, there were 7 on which serious interruptions to the flow of vehicles occurred. These were deleted from the vehicle flow data, and the peak curve for the remaining 12 "accident-free" days was calculated.

At shortly before 5:00 PM, the average hourly rate of flow for the accident-free days was at 7,100 vehicles, compared with 6,700 vehicles for all 19 days. The difference narrowed until about 5:45 PM, when the curve for the accident-free days dropped below the curve for all days. From this time, the accident-free hourly rate was from 200 to 400 vehicles below the total curve until 6:30 PM when the counts ceased.

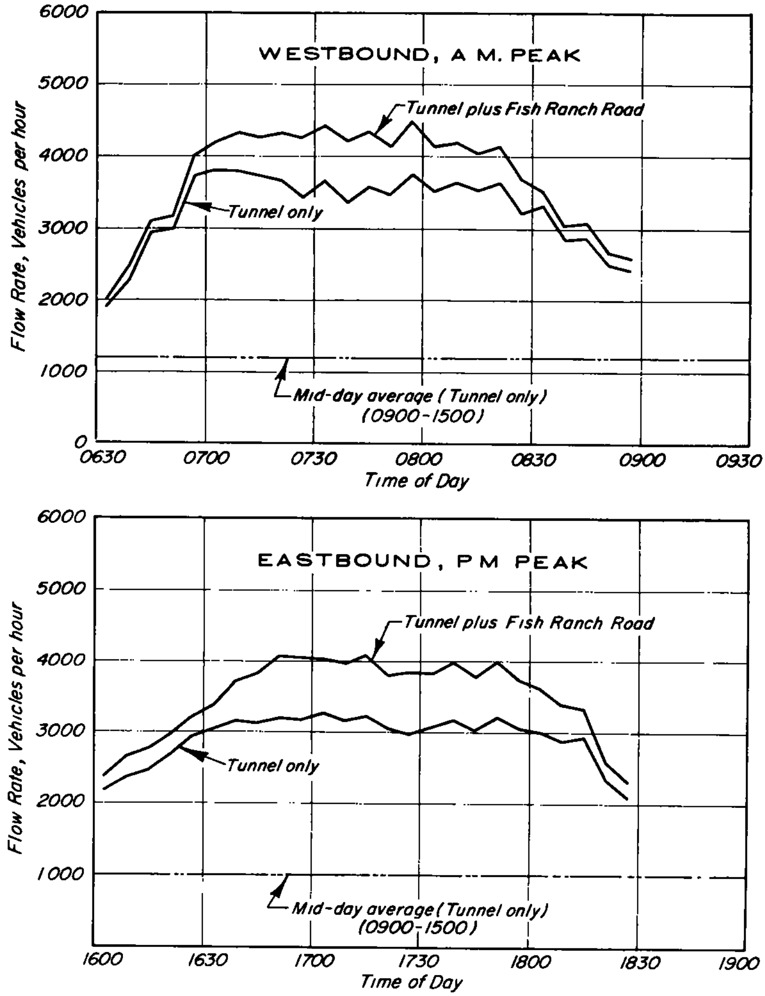


Figure 4. Peak period traffic flow, Caldecott Tunnel.

The "accident-free" days were not, of course, free from the normal stalls and minor delays which daily ration the flow of traffic. It seems reasonable to say that the effect of serious accidents, distributed over both accident and accident-free days, is a reduction of at least 5 percent in capacity; the total effect of all kinds of obstructions is a reduction of at least 10 percent in capacity. The latter conclusion is reached by comparing morning and evening flow rates.

The total volume curve declines slightly after reaching a maximum at 5:00 PM. It is believed that this was caused by the increase in the number of heavy trucks and buses on the lower deck after 5:00 PM; this subject will be further explored in the next section. Total volume fell abruptly after 5:30 PM when the lower deck was closed to passenger cars. The upper deck flow remained fairly constant until after 6:00 PM.

Posey Tube AM Peak. —Figure 3 shows an overlapping of the southbound and northbound peak flows on the Tube, but the southbound peak is largely finished by the time that northbound traffic reaches its maximum size.

Traffic headed south is moving out of Oakland, away from the central city core. The commuters are traveling mainly to the large naval air station and industrial plants in Alameda. In the opposite direction, the central district of Oakland is the principal destination.

Posey Tube PM Peak. —In the afternoon, the northbound peak, representing the departure of naval and industrial employees from their jobs, occurs first. From about 3:45 PM until after 5:00 PM, the Tube operates at full capacity in this direction, a rate of about 1,350 vehicles per hour. As southbound traffic increases to its maximum size, the northbound flow declines rapidly.

At their maximum, the peak volumes are no more than double the midday rates of flow, much less of an excess than at the Bay Bridge or the Caldecott Tunnel. One can imagine that if both peaks occurred in the same direction each morning and afternoon, the size of the combined peak would be very substantially greater—if road capacity permitted.

Caldecott Tunnel AM Peak (Westbound). —Unlike Posey Tube, the peak flow through the Tunnel is practically all in one direction. The morning traffic in the Tunnel reaches the capacity of the highway at 7:00 AM and continues at this rate until almost 8:30 AM. There is a constant queuing of cars at the eastern approaches during this entire period, which serves to divert vehicles to the inferior Fish Ranch Road. Even with the severe restraint of Tunnel capacity upon the peak rate, the maximum flow (including Fish Ranch Road) is $3\frac{1}{2}$ times the midday rate, illustrating the importance of the Tunnel as a commuter facility and explaining why the peak percentages of daily traffic are exceptionally high despite extended traffic congestion.

Caldecott Tunnel PM Peak (Eastbound). —The Tunnel cannot operate at full capacity in the eastbound direction because there is no third traffic lane at the eastern end to absorb the vehicles from Fish Ranch Road. Therefore, the maximum flow, including Fish Ranch Road, is lower than in the westbound direction. The rate of flow, about 4,000 vehicles per hour, indicates the capacity of the two downhill lanes east of the Tunnel to move vehicles after Fish Ranch Road has merged.

The peak is spread out for a period lasting almost two full hours. One of the worst cases of traffic congestion in the Bay Area may now be found on the western approaches to the Tunnel. Long queues are a daily event on all approach roads.

It has actually been recorded, in each of the surveys, fewer total vehicles during the afternoon peak period between 4:00 and 6:30 PM than in the morning peak between 6:30 and 9:00 AM, including the Tunnel and Fish Ranch Road. This is most unusual. Typically the afternoon journey-from-work commuter travel is swollen by a variety of other travel purposes such as shopping, whereas the morning peak is almost exclusively a journey-to-work movement. The data suggest that the severe afternoon traffic conditions tend to divert nearly all travel which is not tied to employment hours to off-peak travel periods; it also may induce a number of commuters to use the extremely roundabout highways passing through the hills many miles to the north or south of the Tunnel.

## OTHER DATA

A brief review of other information collected about various factors that affect total vehicular traffic volumes in peak periods is presented here. These are (a) the proportion of heavy vehicles, (b) the occupancy of automobiles, and (c) public transit riding.

### Heavy Trucking

The presence of heavy vehicles in the traffic stream is an important factor in the capacity of the highways in this study because of the grades on all three facilities. The time and directional pattern of the heavy truck movement has some interesting implications for capacity standards.

As used in this section, the term "heavy trucks" refers to single-unit freight vehicles with more than 4 tires and to truck-trailer combinations. The lightweight trucks usually move fast enough to use no more road capacity than passenger cars, and a large number of them carry commuters rather than freight during the rush hours.

On all three facilities, the percentage of total vehicles that are heavy trucks drops considerably during the peak period. This is a common observation made on urban highways and needs no comment here.

Bay Bridge Trucking. —The Bridge's strategic location in the heart of a large metropolitan area, and as a link in a major intercity highway network, is responsible for a large volume of truck travel throughout the day. The peak rates of flow are shown in Figure 5.

In the morning, no sooner was the lower deck closed to automobile traffic than a sudden upsurge occurred in truck volume. Over a 20-min period, the rate of flow doubled and, at its maximum point, far exceeded the midday average. At 9:00 AM, the flow was declining; it leveled off at around 9:30 AM.

In the afternoon, the truck volumes rose in moderate degree just before the lower deck was opened to automobiles. Then, during the height of the automobile peak, the volume dropped sharply. By 5:00 PM, the volume had returned to the midday average—a fact which, combined with the increased volume of buses about this time, was probably the cause of the mild decline in total Bridge vehicular traffic shown in Figure 2.

After the lower deck was closed at 5:30 PM, there was a rise in heavy truck traffic. This time pattern was observed on each of the individual days on which classification counts were taken, but the curve in Figure 5 understates the magnitude of the fluctuation because it does not occur at exactly the same time each day. We averaged the minimum and maximum 6-min heavy truck volumes recorded on each day between 4:00 and 6:00 PM were averaged and found to range from 100 to 500 trucks per hour.

Congestion is costly to motor trucking, in wages and other operating expenses, and it is logical to find evidence that truckers try to avoid the worst of the peak travel conditions. In this particular instance, it does not appear that the afternoon fluctuation existed before the lower deck was made available to automobiles in 1953. At that time,

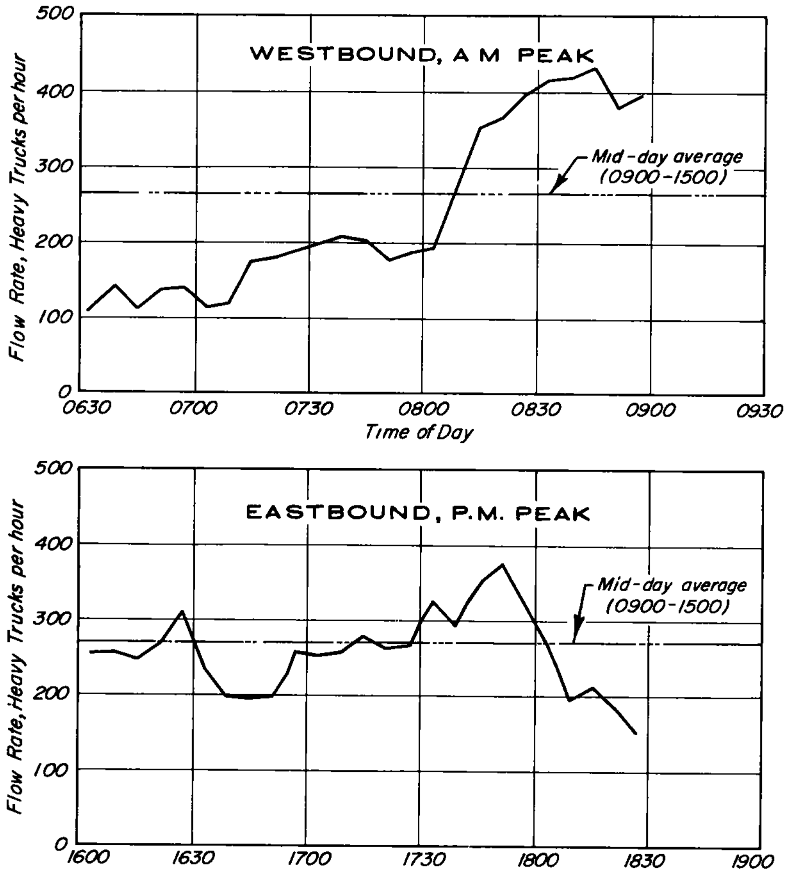


Figure 5. Flow of heavy trucks and combinations, Bay Bridge.

which was in the midst of a transit strike, the motor carriers voluntarily agreed to stay off the Bridge, if possible, during the maximum travel periods. Possibly this arrangement was continued unofficially after the strike was ended and the lower deck remained open to passenger cars.

Caldecott Tunnel Trucking. —On this suburban route, trucking is relatively light in volume; it is composed mainly of local commodity distribution. In the morning the majority of heavy trucks are moving outward from central city origins to the suburbs; in the afternoon they are returning. This movement is in the opposite direction to the primary direction of person trips.

At the rush hours, this directional difference is considerable. The average number of heavy trucks observed during the $1\frac{1}{2}$-hr periods in the morning and afternoon when Tunnel capacity is used to its absolute maximum in the peak direction was calculated. (Table 5). There are almost three times as many heavy trucks moving in the direction counter to the main vehicle peak flow as in the peak direction. Again, the conclusion seems warranted that rush-hour congestion discourages truck usage.

TABLE 5

AVERAGE NUMBER OF HEAVY TRUCKS USING CALDECOTT TUNNEL

| Time Period | Heavy Trucks (avg.no.) | |
|---|---|---|
| | Westbound | Eastbound |
| 7:00-8:30 AM | 28 | 75 |
| 4:30-6:00 PM | 83 | 31 |

Posey Tube Trucking. —There is no notable volume of heavy trucks through the Tube at peak periods. After 4:00 PM, the hourly rate of flow is less than one-half the midday rate in both directions.

## Person Travel

The rate of automobile occupancy and the percentage of people using public transport determine how many persons travel in relation to the number of vehicles. Only short mention is made of the data collected on these subjects, pending a more thorough analysis.

Occupancy. —If there are fewer persons per car during the peak period, the size of the vehicle peak flow will be greater, or the spread of the peak wider. On the three roads in this investigation, occupancy samples were taken between 6:30 AM and 6:30 PM, and the peak period occupancy rate was generally found to be more than in the off-peak. But a notable difference between peak and off-peak rates was found only for the Bay Bridge.

The average occupancy over the entire 12-hr period on each facility is given in Table 6. For the peak direction, the Bridge rate rises to about 1.95 persons, both in the morning and in the afternoon peaks. Toll charges and the cost of all-day parking in San Francisco probably influence these rates.

On all three highways, the occupancy rate drops sharply in the later stages of the morning peak and does not regain the average level until after 10:00 AM.

TABLE 6

AVERAGE OCCUPANCY OVER ENTIRE 12-HR PERIOD

| Test Area | Persons per Vehicle |
|---|---|
| Bay Bridge | 1.67 |
| Posey Tube | 1.52 |
| Caldecott Tunnel | 1.46 |

Transit Riding. —The transit peak flow at the Bay Bridge occurs in the last half of the hour in which the highways are used by vehicles to their maximum capacity. Owing to this fact, the profile of persons movement presents much more the aspect of a peak than the curve for vehicle flow. On the Bridge, there is an actual increase in total person movement between 5:00 and 5:30 PM at the same time that the volume of vehicles, and the number of passengers in automobiles, is decreasing. At the Caldecott Tunnel, transit passenger counts were not feasible, but the record of bus movements there leads to the same finding in the afternoon peak.

There appears to be a fairly good coincidence between the transit and vehicular time patterns on Posey Tube in both directions. However, in the morning there is a much larger volume of persons on transit traveling northbound, into Oakland from Alameda, than in the opposite direction. In the afternoon, the outflow, southbound, from Oakland is considerably larger than the northbound travel from Alameda. Thus, although the total volume of vehicles over the whole peak period is not greatly different in each direction, the primary movement of persons is in the direction of Oakland in the morning and away from Oakland in the afternoon.

## CONCLUDING REMARKS

This presentation has been largely descriptive. It was meant to show the peak patterns of vehicle movement on highway facilities that are utilized to their fullest capacity over lengthy time intervals during the regular morning and evening urban commuter rush periods. At this stage of the study, there is no wish to comment on the possible changes that might occur when the ceilings on road capacity are raised; however, several suggestions may be offered about the effects of sustained traffic congestion on the spread of the peak and the total volume of peak period traffic.

1. Vehicle congestion has caused a rather considerable use by passenger cars of "inferior routes" on the Bridge and at the Tunnel. The upper deck of the Bridge, which was intended to carry all automobile traffic, is almost completely filled in the peak direction from before 7:00 until after 8:00 AM, and from 4:00 until after 6:00 PM. Tunnel capacity is fully used for approximately the same lengths of time during the rush hours.

It is difficult to imagine how far peak usage might have spread if neither the lower deck of the Bridge nor Fish Ranch Road had been available to absorb some of the traffic excess. These alternatives have made additional vehicle peak volumes possible; and it is reasonable to think that if they were not open to traffic, the total number of vehicles appearing during the peak period would be lower, particularly on the Bay Bridge.

2. Stalls and delays associated with intense vehicle congestion act to spread the peak by causing sporadic queuing of cars. They may also reduce the total peak volume on the Bay Bridge because they are frequent occurrences whose probability enters into driving decisions. It seems important that any concept of "possible" highway capacity include an allowance for the frequent repetition of delays and stalls as one of the average conditions of extreme traffic congestion.

3. The peak period data suggest that extreme congestion tends to shift travel in some trip-purpose categories. This seems evident for motor trucking, for whom the costs of congestion are immediately apparent in monetary values. An absolute decline in truck flow, as well as a reduction in the percentage of trucks in the total flow of vehicles, has been found on all three of the study facilities during the maximum vehicle peak.

4. It should be recognized, however, that there is a natural spread of the peak which is fairly independent of transport media. For example, factor employees tend to arrive and leave their jobs earlier, and retail store employees later, than the average. It is likely, too, that the spread of the peak has been encouraged by the convenience of commuting by automobile, as compared with public transit. These inferences seem warranted by the different times of the northbound and southbound peaks at the Posey Tube and by the relation of the peak in transit passengers to the vehicle peak found on the Bridge.

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