An Evaluation of Ramp Control on the Harbor Freeway in Los Angeles

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This paper describes a ramp control project on the 8-lane Harbor Freeway in Los Angeles. Congestion occurred each weekday in the 4 outbound lanes during the evening peak period, while the adjacent parallel streets were relatively uncrowded. The control project is designed to reduce total travel time through the freeway corridor by metering 5 on-ramps and closing 1 ramp in a 5-mile section during the peak period.

Some unusual techniques are being employed: Buses are allowed to bypass ramp queues and to make left turns where other traffic cannot; storage of queued vehicles on a frontage road is carried back across an intervening major thoroughfare by timing the intersection signal so that the intersection itself remains clear; and, at one location, storage room is increased and high metering rates are made possible by the release of vehicles 2-abreast at the ramp signal.

Results show that freeway users are saving about 1,000 vehicle-hours per day against a loss, or increased travel time for diverted or delayed ramp traffic, of about 130 vehicle-hours.

•IN SEPTEMBER 1968, the California Division of Highways, with the cooperation of the Los Angeles City Traffic and Police Departments, began a freeway ramp control project on the southbound Harbor Freeway in south Los Angeles. The Harbor Freeway is a major 8-lane facility extending 22 miles from downtown Los Angeles to San Pedro. Basically, the project involves limiting on-ramp traffic in a 5-mile section of the 4 southbound lanes during evening peak hours (Fig. 1). The purpose is to reduce delay to freeway users and gain optimum use of the freeway and street system during the rush hours.

The science of controlling ramp traffic to reduce total travel time (freeway and surface streets) is comparatively new. However, the Harbor Freeway project is not the first project of this type. A similar, although smaller, system has been in effect in Los Angeles on the Hollywood Freeway for more than a year; other projects are in operation in San Diego, Chicago, Detroit, and Houston. The Harbor Freeway was selected as the first major effort in Los Angeles because of the high probability of success. The availability of relatively uncrowded parallel streets in the Harbor Freeway corridor and excess capacity on the downstream freeway sections were promising indicators that more good could be done more quickly here than anywhere else in the Los Angeles area. Also, several on-ramps in this area adapted themselves rather easily to metering (i.e., available frontage road and storage area). Control of 6 on-ramps to the southbound Harbor Freeway is accomplished by various means that were determined by an in-depth study requiring application of basic traffic engineering principles at each ramp. One

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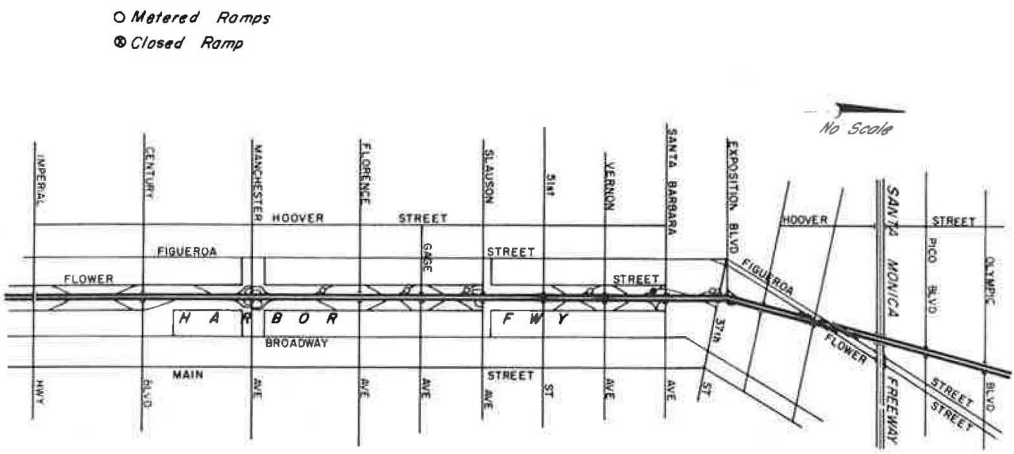

Figure 1. Location of ramp control project.

ramp is closed during the control period by the use of barricades, 2 ramps are controlled by platoon metering, and 3 ramps are controlled by single-car metering. Generally, the control period is from 3:45 to 5:45 p.m. each weekday.

This paper is primarily an evaluation of the ramp control project, but it also briefly describes the planning prior to implementation. The conclusions drawn are based on extensive data collected before and after the project was initiated.

CONDITIONS BEFORE CONTROL

Freeway

Prior to the ramp control, congestion was caused by simply too much traffic trying to use the southbound Harbor Freeway south of Exposition Boulevard. Typical weekday operation of the freeway before control is shown in Figures 2, 4, and 5, representing density, speed, and volume. (Figure 3 shows density after control.) Congestion normally started about 3:45 and lasted until after 6:00 and extended from Manchester Avenue to just north of Adams Boulevard.

The density contours (Fig. 2) indicate 2 distinct congested areas—1 south and 1 north of Slauson Avenue. The congestion was the result of excess demand of approximately 500 vehicles per hour (vph) affecting 2 key sections. The most southerly bottleneck was where the Florence Avenue on-ramp traffic joined an almost full freeway and caused excess demand for the section. This caused congestion that extended to and upstream of Slauson Avenue. The second major bottleneck was caused by Vernon Avenue on-ramp traffic joining a near-capacity flow to create excess demand for an upgrade (800 ft at approximately 5 percent) approaching Slauson Avenue.

Total delay on a typical weekday was about 60,000 vehicle-minutes from 3:45 to 6:15 p.m. Maximum delay to individual vehicles was more than 6 min upstream of Slauson Avenue and about 3 min between Slauson and Manchester Avenues.

Figure 4 shows travel times and speeds throughout the evening period; travel times before control were frequently greater than those shown. Average speeds for the entire trip from 30th Street to Century Boulevard were as low as 15 mph, with much stop-and-go driving. A freeway trip from 30th Street to Century Boulevard frequently took about 17 min during the peak period.

Typical peak-period flow rates, shown in Figure 5, represent conditions from about 5:00 to 5:30 p.m. At this time, the entire length upstream is controlled by the capacity at the most southerly bottleneck. For this reason, throughput upstream of Manchester Avenue was considerably below capacity of the various sections. Before 5:00 p.m.,

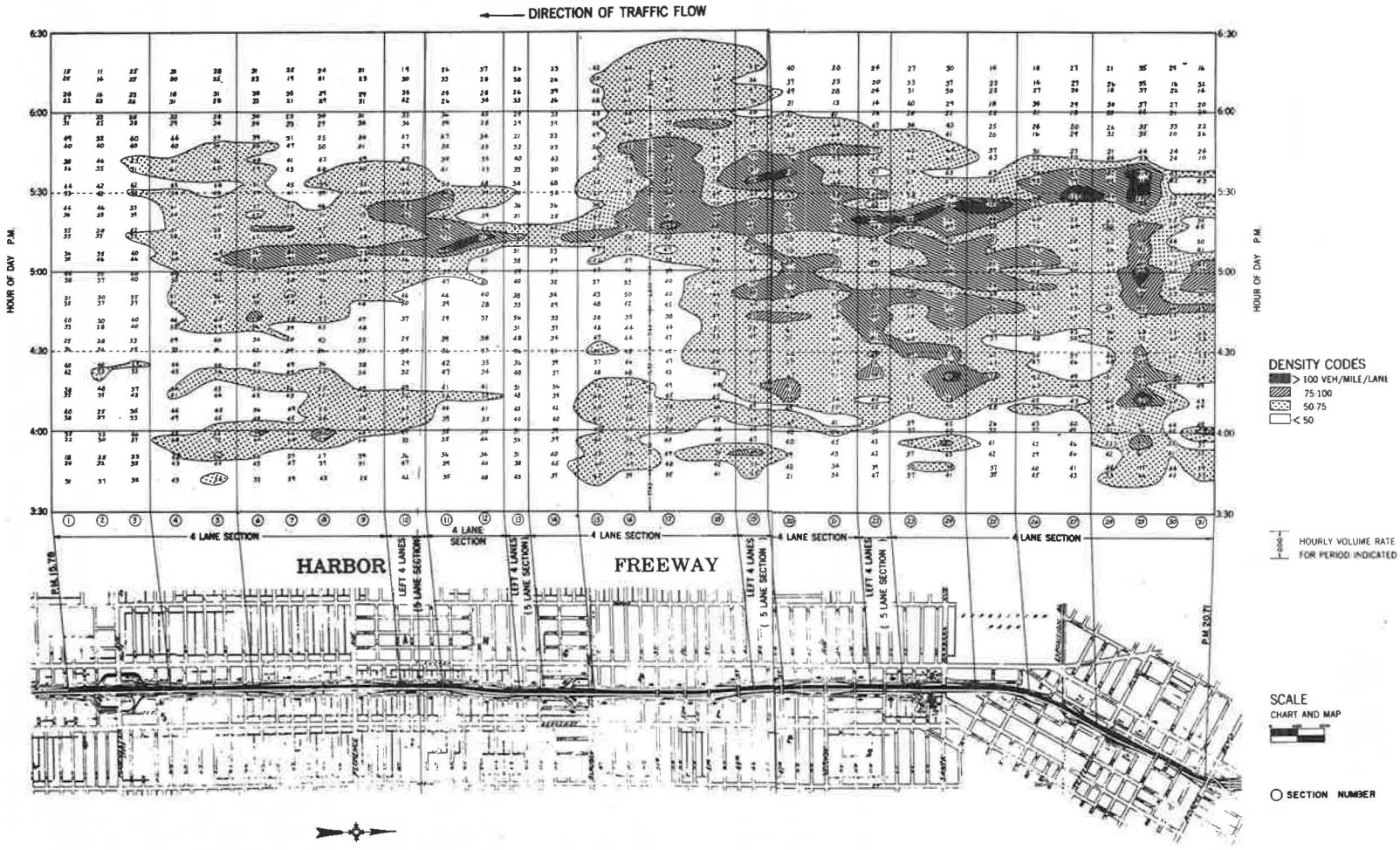

Figure 2. Density before controls on the southbound Harbor Freeway from 3:30 to 6:30 p.m., Tuesday, October 25, 1966.

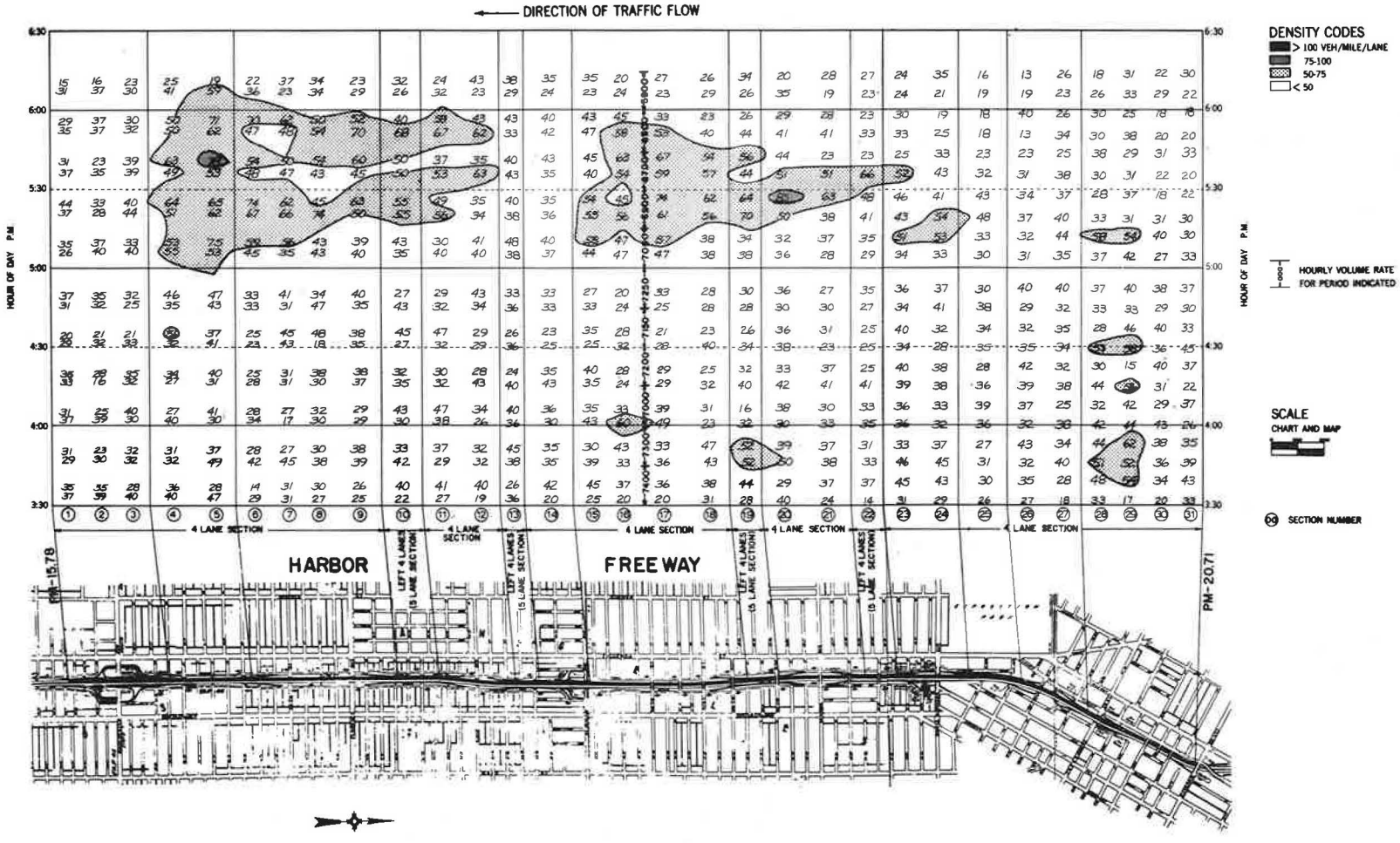

Figure 3. Density after controls on the southbound Harbor Freeway from 3:30 to 6:30 p.m., Wednesday, October 16, 1968.

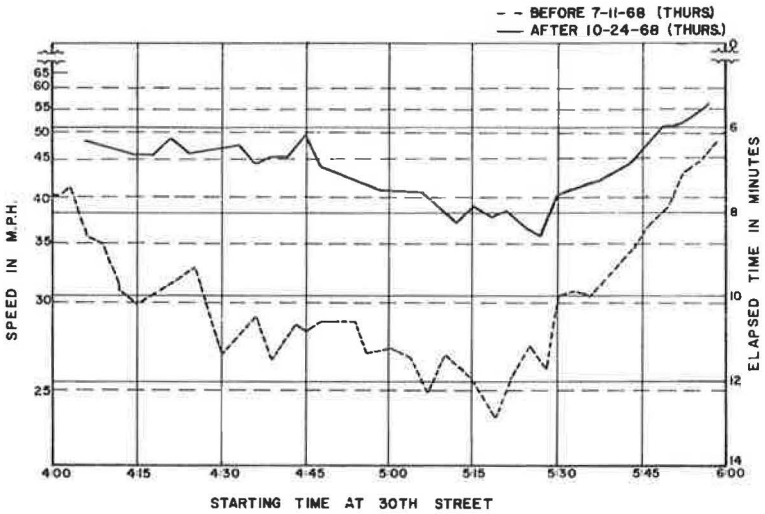

Figure 4. Travel time and speed on the southbound Harbor Freeway between 30th Street and Century Boulevard (5.08 miles).

conditions were somewhat similar, except that the Slauson Avenue grade was an independent bottleneck with flow rates of about 7,100 vph.

Surface Streets

Preliminary data indicated that the parallel streets, Broadway and Figueroa, would be the best alternate routes for diverted traffic. Both of these are major thoroughfares. Broadway has 4 lanes, a painted median, and left-turn pockets. Figueroa has the same and, in addition, a parking lane on each side with restricted parking during peak hours.

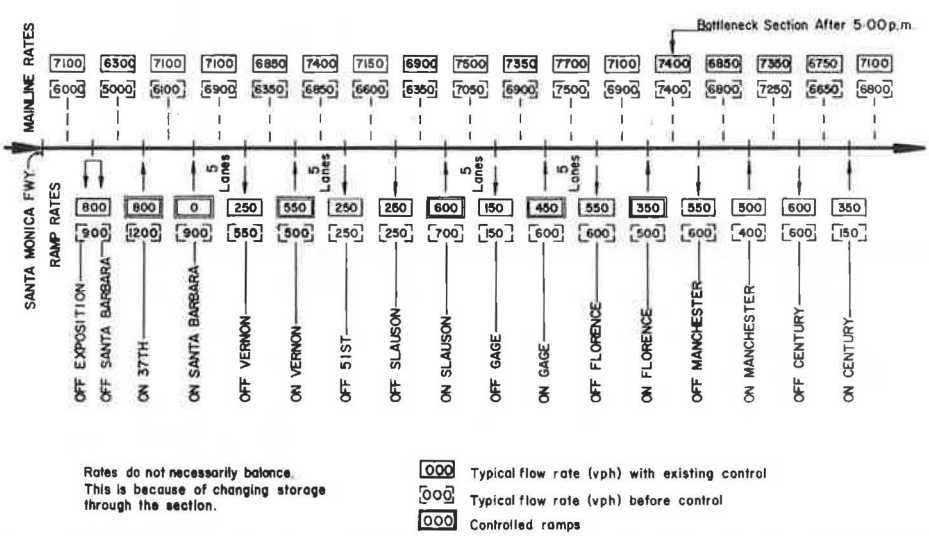

Figure 5. Typical peak-period flow rates from approximately 5:00 to 5:30 p.m.

westbound 37th Street because these turning movements would block eastbound 37th Street traffic. The metering rate of 650 to 850 vph is too great for single-car metering. Platoon metering was the answer, and it has worked well. The 37th Street on-ramp was particularly adaptable to platoon metering because of a long collector road. This collector road also handles off-ramp traffic that tends to break up platoons and approximate single-car metering.

Santa Barbara Avenue

The Santa Barbara Avenue on-ramp (Fig. 7) had to be closed to all traffic, except buses, because of inadequate storage for metering.

Vernon Avenue

The Vernon Avenue on-ramp (Fig. 8) has a minimum storage area, so normal metering at the ramp would cause interference with Vernon Avenue traffic. Closure of the ramp would be too restrictive. Therefore, it was necessary to devise a method for control that allowed approximately the existing volume to enter without an extensive queue forming at the ramp. Metering signals were placed on the west frontage road just upstream of the Vernon Avenue off-ramp. These signals intercept traffic coming from Santa Barbara Avenue and release an amount slightly below the metering rate at the Vernon Avenue ramp signal. This allows the right turn from eastbound Vernon Avenue to reach the on-ramp. Initially, the left turn from westbound Vernon Avenue was prohibited because the ramp queue might have kept this traffic from clearing the intersection. Now the left turn has a separate green phase and pocket lane. Traffic on the west frontage road approaches in 2 lanes and is released in 2-lane platoons from the front-

Figure 7. Santa Barbara Avenue on-ramp that is closed because of lack of storage space. Buses have always had a separate entrance to the ramp and can be easily allowed special access. Ramp is closed by hand-placed barricades that will be eventually replaced by automatic "pop-ups". Queue on Figueroa Street is the result of preferential signal timing for Santa Barbara Avenue traffic. Although not related to the project, green time on Santa Barbara Avenue has been increased since the start of controls. This is the key intersection in the entire project area.

Figure 8. Vernon Avenue on-ramp where single-car metering from 2 lanes is used because of limited storage space. Metering signals are used on the 1-way frontage road to keep stored traffic from blocking the Vernon Avenue intersection. Green phases of the frontage road and Vernon Avenue signals coincide. Queue on the northbound off-ramp is unrelated to project; queues were a frequent occurrence before controls.

Average speeds on both Broadway and Figueroa were 15 to 30 mph. A trip from 30th Street to Century Boulevard via Figueroa took an average of about 15 min and a peak of 19 min. Hourly volumes on southbound Broadway ranged from 1,200 vehicles at 57th Street to 850 vehicles at 85th Street. On Figueroa, volumes were as high as 1,400 vehicles at 57th Street and diminished to about 1,100 vehicles at 85th Street.

PLANNING

The basic theory used in planning was a demand-capacity analysis on the freeway. For 2 bottlenecks that were located, capacity was determined, demand was estimated, and a ramp control plan was developed that would reduce demand to what each section could handle. A more comprehensive discussion of the theory of ramp control is presented in another paper (1).

An origin and destination survey of traffic using the ramps within the critical area was necessary for an accurate prediction of the pattern of traffic diversion caused by control. We were able to predict that a high percentage of the traffic subject to control would enter at upstream locations and that parallel facilities would not become overloaded.

During the planning phase, meetings were held with interested individuals and local agencies to inform them of our efforts. The ramp users were informed by handouts the week before control began. Alternate route signs were placed on the city streets to aid the diverted traffic.

One of the most important phases of the project was planning the method for control at each ramp location to determine the amount of traffic that should be let on and the means for minimizing the effect of control on "innocent" traffic. When severe metering was necessary, we knew that time and not distance would determine the queue length. In other words, the driver is concerned with the amount of time it takes him to enter the freeway, rather than with the distance he must travel. Therefore, if a short queue were desired, then a more restrictive metering rate had to be used. Increasing the delay to the individual motorist causes him to seek an alternate route.

The metering signals operate on a fixed-time basis with up to 3 different rates operated by a time clock; a 3-dial controller is used. The rates are set based on "typical" conditions or traffic patterns. The system is not traffic-responsive. In the following is a discussion of some of the major points considered in planning the controls at each ramp.

Figure 6. 37th Street on-ramp where platoon metering is used because of high metering rates used. Most traffic comes from southbound Flower Street and is stored in the left-turn lane upstream of Exposition Boulevard. Left turns to the ramp from westbound 37th Street are prohibited because they would interfere with eastbound 37th Street traffic. Right lane of the ramp is striped and signed for buses and emergency parking only. Congestion in northbound lanes is the result of a previous incident in the northbound lanes and is not affecting southbound traffic at this time.

37th Street

The 37th Street on-ramp (Fig. 6) was the most critical on the project. It is the first on-ramp south of the Santa Monica Freeway and as such has a very high demand (1,200 to 1,300 vph). Limiting this traffic to 650 to 850 vph could have very seriously affected nonfreeway traffic on 37th Street and Flower Street, and possibly Exposition Boulevard and Figueroa Street. This problem was minimized by the prohibition of left turns into the ramp from

age road metering signals. These metering signals are interconnected with the signals at the Vernon Avenue and west frontage road intersection. The green phases of the two sets of signals coincide so that metered traffic does not have to stop at Vernon Avenue.

In order to handle these two lanes of traffic, the Vernon Avenue on-ramp entrance was widened to 2 lanes. The ramp metering signals release 1 car at a time from each lane. The ramp signals are located near the entrance from the frontage road leaving most of the ramp available for the 2 cars to merge into 1 lane before they reach the freeway acceleration lane. Initially, it was difficult to maintain single-car operation, but this was partially resolved through the use of signs that read METERED—ONE CAR PER GREEN THIS LANE. With these signs, violations are around 10 percent; without the signs, they were 15 to 20 percent.

Slauson, Gage, and Florence Avenues

On the basis of traffic volumes before control at Slauson, Gage, and Florence Avenues, metering appeared to be necessary at these ramps only after 5:00 p.m. However, diversion from upstream ramps before 5:00 p.m. was anticipated (which in fact happened), so the metering periods at these ramps were set to approximately coincide with those for upstream ramps (3:45 to 5:45 p.m.). This holds the ramp volumes to about the same as they were before control.

Manchester Avenue and Century Boulevard

On-ramp volumes at Manchester Avenue and Century Boulevard were not so high that they had to be metered; however, signals were placed at each in anticipation of an increase from diverted traffic. Volumes have increased, but not to the point that metering is necessary.

Buses

Alterations were made to provide special access for buses. At 37th Street (Fig. 6), the right lane of the ramp was striped and signed for buses only. This allows them to bypass the ramp queue. The ramp configuration at Santa Barbara Avenue, where buses have always had a separate entrance to the ramp (Fig. 7), made the access of buses and prohibition of other vehicles quite easy.

CONDITIONS AFTER CONTROL

Freeway

The before-and-after density data (Figs. 2 and 3) were used to estimate freeway travel times. These data give a good picture of the amount of congestion between Adams Boulevard and Manchester Avenue on typical days. There is considerable congestion upstream of Adams Boulevard, and this has not changed much with control.

Total freeway travel time before control from 3:45 to 6:15 p.m. between Adams Boulevard and Manchester Avenue was 188,000 vehicle-minutes per day. Now during the same period, freeway travel time is approximately 128,000 vehicle-minutes, a reduction of 60,000 vehicle-minutes in spite of an increase in the total vehicle-miles of travel.

During the period before control, there were 81,000 vehicle-miles of travel on the freeway. This means that during the total 2½-hour period average speed between Adams Boulevard and Manchester Avenue was 2.32 min per mile (188,000 divided by 81,000) or 25.8 mph. During the period after control, there were approximately 86,000 vehicle-miles of travel, and average speed was 1.49 min per mile or 40.3 mph. Without the extra vehicle-miles of travel, the after travel time would have been 81,000 times 1.49 or 121,000 vehicle-minutes. Savings on the freeway, therefore, were actually 67,000 vehicle-minutes for the base or original amount of travel instead of the calculated difference of 60,000 vehicle-minutes.

The extra travel on the freeway is caused by about 900 vehicles that now enter the freeway upstream of the control section instead of at the controlled ramps as they for-

merly did. These trips should add to the savings, although to determine their actual savings is virtually impossible. Probably, where there is enough backtracking, some of these trips actually lose time compared to the time they took before control. However, we are sure the net result is added savings because (a) the great majority of these extra trips originated north of the control section and (b) their responses to a survey questionnaire indicate they save time. Net savings are not as great as noted, however, because there is delay to diverted traffic and to vehicles at the ramp metering signals.

Approximately 500 vehicles no longer use controlled ramps where delay may be experienced. They are staying on surface streets to Manchester Avenue or Century Boulevard, or staying off the freeway completely. These trips will average about 2 minutes longer than they formerly did on the freeway for a total delay of 1,000 vehicle-minutes. This is a conservative estimate as it assumes that all this traffic starts upstream of 37th Street and goes all the way to Century Boulevard, but, actually, some of it is on streets a lesser distance and would not suffer as much delay.

Queue lengths versus time were plotted for each controlled ramp on a typical day. With these, the delay caused by the signals was estimated for each on-ramp. Total delay at the ramps is about 9,000 vehicle-minutes per day. The net savings then to traffic in the freeway corridor is at least 50,000 vehicle-minutes per day from the ramp control.

Generally speaking, individual motorists who enter the freeway at 37th Street or Vernon Avenue save time even though they must wait at the metering signals. They more than make up their lost time at the signal by increased speeds on the freeway. Those who enter at Slauson or Gage Avenue break even; their wait at the ramp is about the same as their gain on the freeway. Those entering at Florence Avenue are the only ones who actually lose time because they were entering at the head of the line before control.

Figure 4 shows travel time and speed for individual trips through the control section. These were obtained by photographic methods (taking pictures of traffic at points along the freeway and matching cars in the pictures to get travel time) and floating car runs. The before data were collected during the summer of 1968 and represent somewhat less congestion than that indicated by the before densities, which are for a day in October 1966. After control, average speed is frequently more than 40 mph. Before control, a trip from 30th Street to Century Boulevard off-ramp could have taken as long as 16 to 17 min (even though the densities do not show this). This same trip now takes a maximum of 7 to 9 min. Conditions upstream of 30th Street have remained about the same.

Before control, about 6,300 vehicles entered the freeway from the 6 controlled ramps between 3:45 and 5:45 p.m. With the Santa Barbara Avenue ramp closed and the others metered, now about 4,900 vehicles are allowed to enter.

Increased input to the control section from the freeway upstream indicates about 900 of the diverted vehicles now enter the freeway upstream of the control. These motorists are probably not backtracking to enter the freeway, that is, their trips originate upstream of the control area. An origin-destination survey made prior to control showed that at least 32 percent of the Vernon Avenue on-ramp traffic would probably have entered upstream had it not been for the freeway congestion. These motorists obviously feel they are saving time if they have changed their routes. It is estimated that now 500 vehicles either stay off the freeway altogether or use a ramp downstream of the controls.

As expected, off-ramp volumes have decreased somewhat since control. Before control, 45 percent of the traffic exiting at Vernon Avenue alone continued south along the freeway corridor. Other off-ramps were somewhat similar. These motorists were either re-entering the freeway downstream or staying off completely to avoid freeway congestion until their desired destination.

Figure 5 shows typical peak-period flow rates on the freeway. These volumes are representative of the period from 5:00 to 5:30 p.m. when the greatest throughput increase is realized. During this period, the downstream bottleneck at the Florence Avenue on-ramp controlled the before period throughput of all upstream sections including the Slauson Avenue grade.

Capacity of a bottleneck cannot change, except in very special cases and then only to a very limited degree. Although there is no conclusive evidence, capacity of the Slauson Avenue grade may have increased slightly because of increased approach speeds, but the rate increase from 6,600 to 7,150 vph shown in Figure 5 does not represent this increase. The low before rate was a result of the downstream bottleneck controlling output during this period.

No doubt, the best overall picture of the changed traffic conditions is the before-and-after densities shown in Figures 2 and 3. The after densities indicate that, before 5:00 p.m., there are only isolated points of densities over 50 vehicles per mile per lane (vml) with the major portion of operation below capacity. This slack allows a natural recovery capacity to dissipate congestion resulting from incidents. After 5:00 p.m., there are still pockets of congestion upstream of both bottleneck sections. Initial metering rates did not eliminate this congestion because they were based on a precontrol condition where input to the section dropped significantly after 5:00 p.m., and off-ramp volumes increased. This condition changed once control began. Input now stays at a high level until 5:20 p.m., and off-ramp volumes actually decreased during this part of the control period.

Surface Streets

Subjectively, traffic conditions on the city streets have not changed appreciably. Trips through the control area on either Broadway or Figueroa Street average about the same time as they did before. Speeds are between 15 and 30 mph. Speeds on the surface streets were obtained by a license plate study that involved recording time and license plate number at key locations. These were then matched to determine elapsed time. Floating car runs were used to supplement these data.

Not all the diverted traffic could be located with the techniques available. No doubt some motorists are using routes other than Broadway or Figueroa Street. However, based on origin-destination data, street patterns, and travel times, Broadway and Figueroa Streets are the best alternate routes for most of the diverted traffic. And the effect on these routes was barely measurable with travel times and volume counts.

An estimated 500 vehicles have been diverted from the freeway throughout the control period. Traffic volumes, obtained at various locations on Figueroa Street and Broadway, show that the volume has not significantly increased at any one location. Five hundred vehicles spread over a 2-hour period and throughout the adjacent streets have easily been absorbed.

RESULTS AND CONCLUSIONS

The project is very successful. Delay to the freeway motorist is significantly reduced, delays to controlled traffic are relatively minor, and travel time on adjacent streets has shown little or no increase. Basically, the ramp control prevents about 1,400 vehicles, which used the freeway during the before period, from entering the on-ramps within the control area from 3:45 to 5:45 p.m. Of these, approximately 900 vehicles now enter the freeway at some ramp upstream, and 500 vehicles are being diverted to surface streets.

Congestion on the southbound Harbor Freeway is almost entirely eliminated south of Exposition Boulevard, except on days when incidents occur and reduce capacity. A minimum average speed of 40 mph is now maintained throughout the control period—with occasional shock waves. This compares with 15 to 25 mph under stop-and-go driving conditions before control. Individual motorists save a maximum of 9 min per through trip on some days, and the average motorist saves 4 to 5 min per trip. The controls benefit not only through traffic, but also drivers that get off the freeway in the control area, depending on where they exit.

Traffic conditions on the parallel city streets, principally Broadway and Figueroa, are practically unaffected by the ramp control. Total travel times and volumes through the control area on either Broadway or Figueroa Street have remained nearly the same.

The net effect of the control project is estimated to be a time reduction on the freeway of about 60,000 vehicle-minutes and increased travel time of roughly 10,000 vehicle-

minutes per day to diverted traffic and traffic waiting at the metering signals. This assumes that travel time has not significantly increased for motorists who have always used city streets. Drivers who formerly entered the freeway in the control area and now enter upstream also save time, but the amount is unknown.

Solicited opinions of users at the Manchester Avenue and Century Boulevard off-ramps show the motorists to be very much aware of, and in favor of, the system. Ninety-two percent of the responses indicated approval. Those entering at the controlled ramps were not as enthusiastic as those entering upstream, but the majority still approved the project. Figure 9 shows a typical response.

The project shows that a relatively small number of vehicles in excess of capacity at key bottlenecks can cause severe and recurrent congestion. In this case, the excess was about 500 vehicles over a 2-hour period.

Significant knowledge has been gained about ramp control from this project. The following are the important points:

1. Planning of control methods is very important and, in this project, was directly responsible for minimum disruption to surface street traffic. The slight sacrifices in the optimum freeway control that sometimes must be made to ensure good street operation are not critical.
2. Platoon merging or random merging of single vehicles has caused no problems.
3. Incidents are very frequent. The entire 5-mile section at times is operating virtually at capacity and any incident in this reach has a drastic effect. When operating at capacity, the storage built up by each incident cannot be dissipated for the rest of the control period. The sharp reductions in metering rates that would be required to dissipate congestion are usually not possible because of the severe congestion that would be caused on surface streets. In fact, unless good information can be given to drivers approaching metered ramps, we do not feel a sharp and nonpredictable (to the driver) fluctuation of metering rates is advisable. Because of the frequency of incidents and difficulty in dissipating resultant congestion, operating at volumes slightly below capacity, if possible, is probably justifiable. This slack allows a natural recovery capacity. In

Where did you enter the freeway: 15:16
SANTA MONICA FREEWAY
(Give name of ramp, street or other freeway. For example: 5th St., 37th St., Pasadena Freeway.)

If you have been a frequent user of the freeway at about this time, please answer the following questions:

Prior to the start of the control project, did you usually enter the freeway at the same location noted above? ☐ Yes ☑ No
If "No", where did you usually enter:
VERNON

Do you think freeway driving conditions, on an average day without accidents, have been improved since the project started: ☑ Yes ☐ No
If "Yes", how much time do you believe you save: 10 to 15 minutes

Comments: Prior to the control project, I entered the freeway at Vernon beaause of the congestion from th Santa Monica & Harbor interchange. Now it is a constant flow from the interchange.

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Figure 9. Survey response of driver that exited at Century Boulevard about 5:20 p.m.

our project this is possible from 3:45 (start of control) to 5:00 p.m. We now operate with some slack during this period. The adjacent streets are at or near capacity only from 5:00 to about 5:30 p.m. After 5:00 p.m. the metering would have to be too restrictive to operate with any slack.

4. This is not a traffic-responsive system. Such a system would provide some additional benefits. However, for reasons we have mentioned, more refined metering rates is not one of them. The primary benefit would be to take advantage of unused capacity downstream of incidents and to allow for major changes in input demands. In other words, we could start and end control at different times more in keeping with actual freeway conditions.

REFERENCE

1. Newman, L., Dunnet, A. M., and Meis, G. J. Ramp Control—What It Can and Cannot Do. Traffic Engineering, Vol. 19, No. 7, June 1969, pp. 14-21.