Traffic Control on a Two-Lane, High-Speed, High-Volume Freeway Entrance

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This report covers efforts to solve a serious traffic problem resulting when holiday-weekend travelers returned to the Los Angeles area. Intolerable congestion on Memorial Day 1966 led to emergency measures on July 4th. A form of ramp control provided partial relief. On subsequent holidays, more sophisticated plans were attempted with a variety of results. The data collected and the observations noted provide a wealth of information on a unique application of ramp control and an emerging philosophy in freeway and expressway operation.

• ON holiday weekends in 1966, traffic returning to Los Angeles from resort and recreation areas north of the city experienced severe congestion at the merge between the Golden State Freeway (Interstate 5) and Sierra Highway (California 14). The interchange between these two routes is located in Saugus Pass, which slices between the Santa Susana and the San Gabriel Mountains just inside the north city limits.

This report covers traffic control techniques used to relieve the southbound merge between Sierra Highway and the Golden State Freeway prior to interim widening, which was completed in the summer of 1967. Practical benefits were sought through recently developed methods for improving freeway operation by controlling entrance ramps. Basic philosophy was derived from on-going research in Chicago and Houston. The results of that work, however, had to be adapted to the unique physical and operating characteristics of the Golden State Freeway-Sierra Highway interchange.

Plans were developed through the cooperative efforts of the City of Los Angeles Traffic and Police Departments, the Los Angeles County Sheriff's Office, the California Highway Patrol, and the State Division of Highways. The nature of the project provided opportunities both to improve traffic and to evaluate techniques of ramp control. The specific objectives were the following:

1. To reduce congestion and delay to motorists using Sierra Highway and the Golden State Freeway during inbound peaks on holiday weekends,
2. To evaluate ramp closing and ramp metering techniques, and
3. To demonstrate ramp control as a tool for improving freeway operation.

DESCRIPTION OF CONTROL PLANS

This section provides some background on the street and highway system controlled and gives a summary of each of the three plans used.

Background

Figure 1 shows the affected street and highway system. Control operations took place on the southbound connector from Sierra Highway to the Golden State Freeway.

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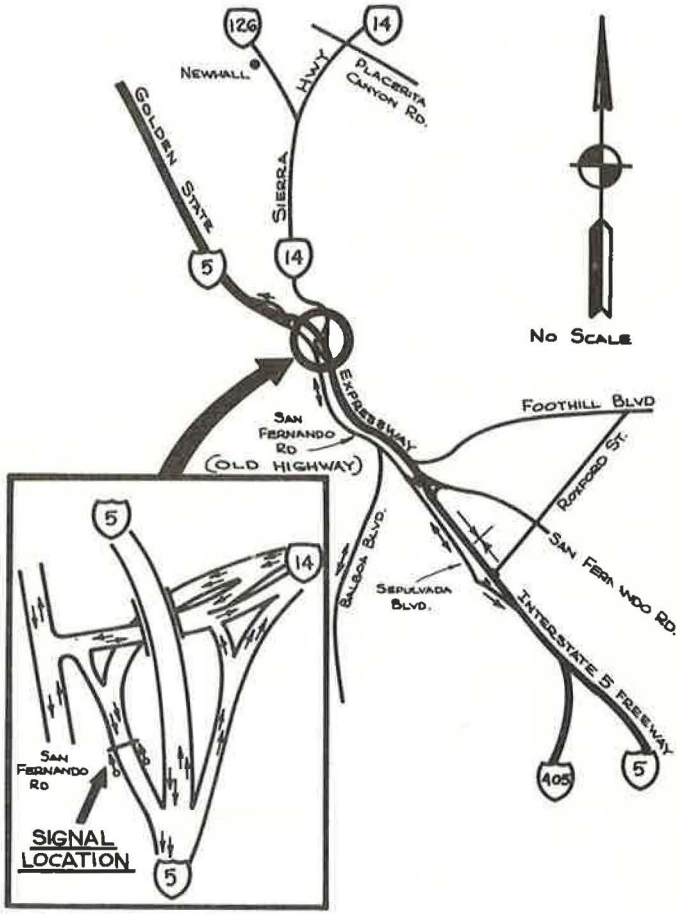

Figure 1. Area map.

The Golden State Freeway, an Interstate route, had been enlarged to eight lanes both upstream and downstream of the existing interchange. Complexity of the future interchange, however, had delayed construction here and only two lanes served southbound traffic in 1966. A frontage road, consisting of the old highway (San Fernando Road) and Sepulveda Boulevard to the south, provided a bypass around this two-lane section.

Figure 2 shows an aerial view of the interchange. A three-level structure carries the Golden State Freeway over the top, Sierra Highway at grade, and the southbound connector underneath. The critical merge occurs where the two-lane connector from southbound Sierra Highway enters the Golden State Freeway's two southbound lanes. The most severe congestion occurred on three-day holiday weekends, such as Memorial Day, July 4th, and Labor Day in 1966. On occasion the Golden State Freeway backed up 10 miles and Sierra Highway as much as 5 miles. No serious congestion developed during normal day-to-day operation, however.

Beginning July 4, 1966, traffic control was used to relieve excessively heavy demand. On this day the connector was closed for several hours and Sierra Highway traffic routed over the old highway. On Labor Day, 1966, Sierra Highway traffic was metered onto the Golden State Freeway by means of manual control. No problems were anticipated for Thanksgiving weekend, and no plans were made for control. The heavy congestion that did develop, however, led to installation of temporary traffic signals on the connector road. Arrangements were made to operate these signals on Christmas Monday in 1966, on New Year's Monday, the first Sunday of trout season, Memorial Day, and July 4th in 1967.

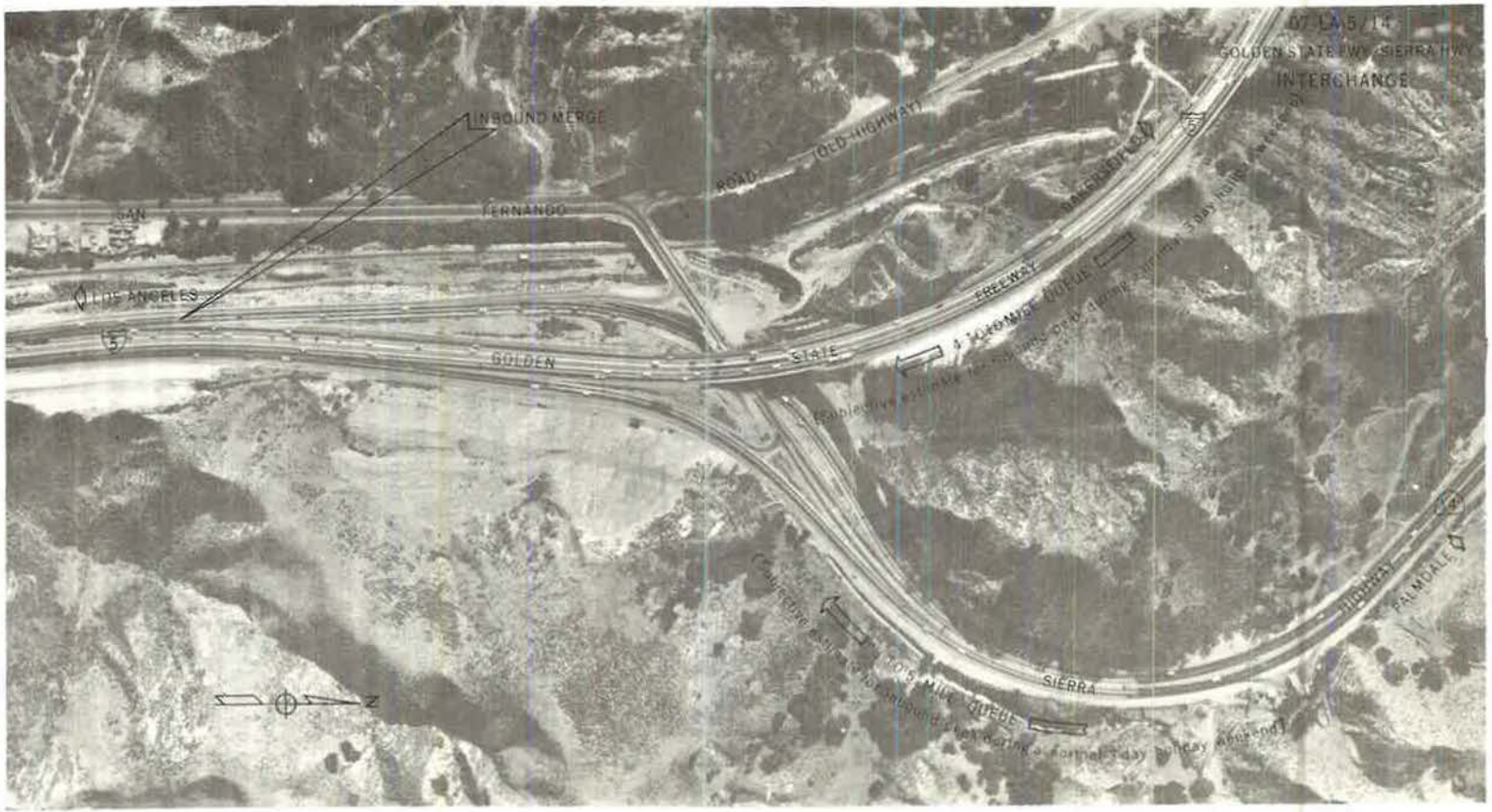

Figure 2. The Golden State Freeway and Sierra Highway interchange.

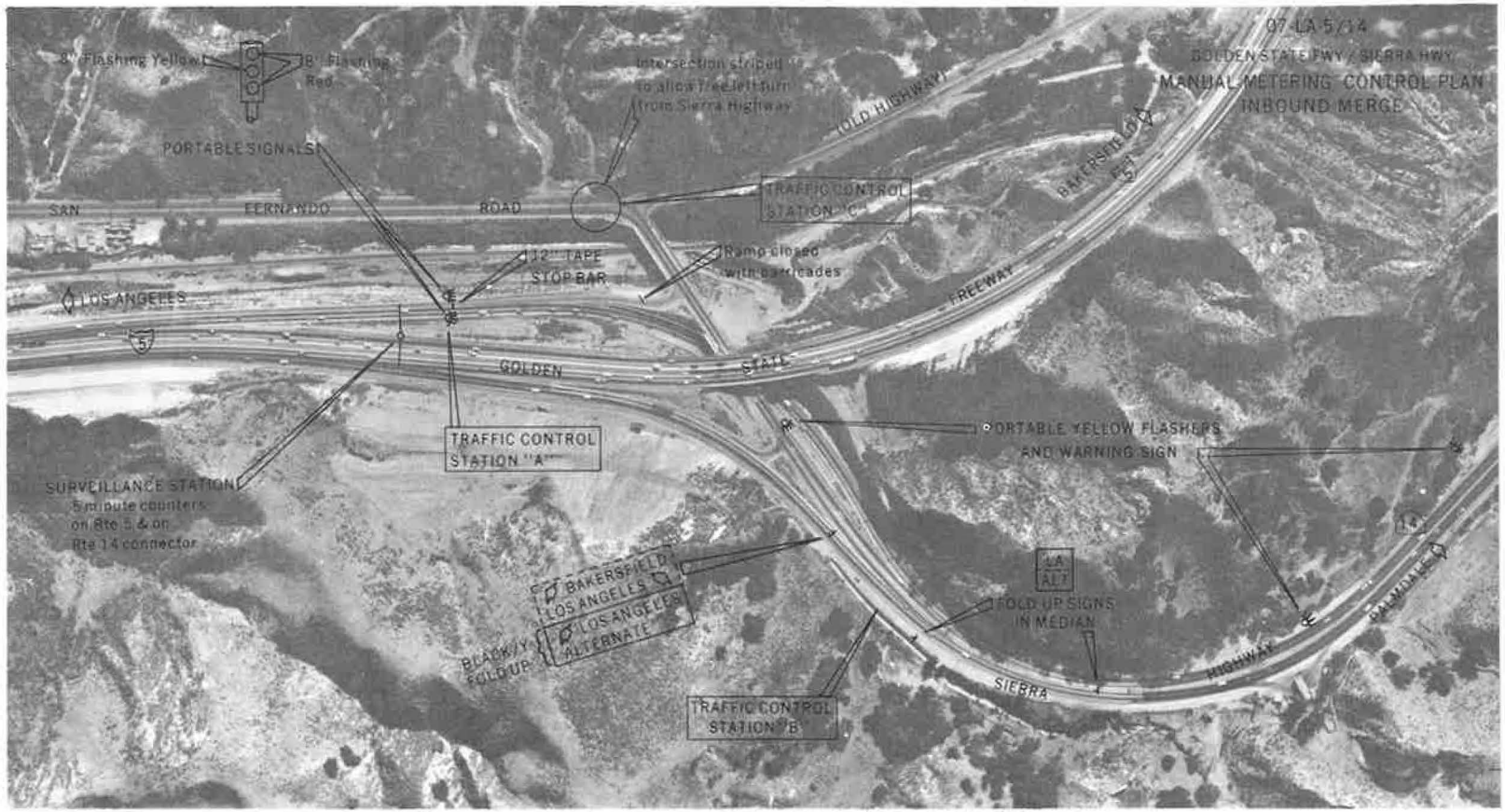

Figure 3. Plan for manually metering Sierra Highway traffic.

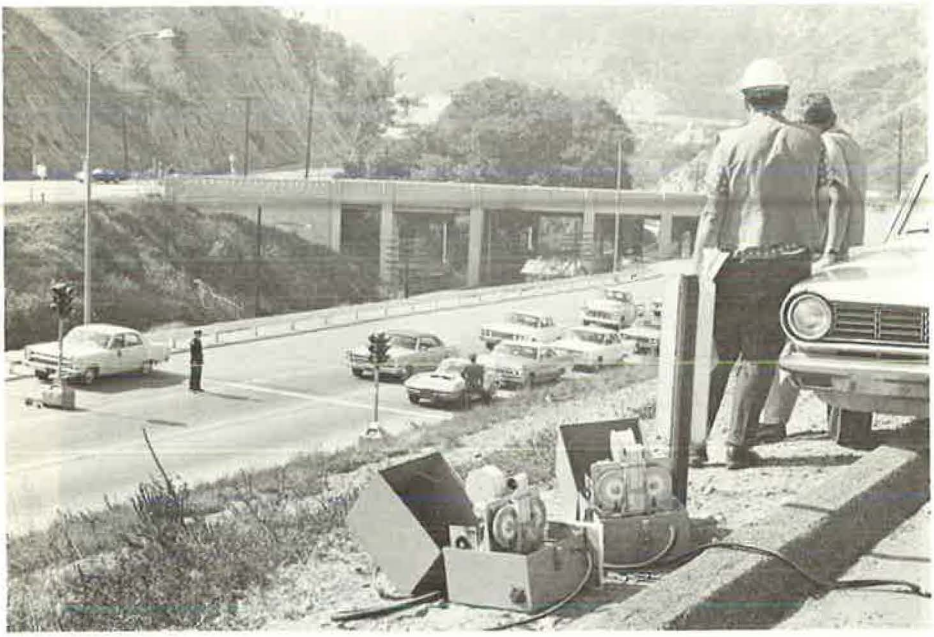

Figure 4. Manual metering control operation.

An interim widening project was completed before Labor Day in 1967. This project provided three lanes southbound instead of the original two. The increased capacity proved adequate to handle peak rates of 4600 vph on Labor Day, 1967. Traffic control was no longer required.

Control Plans

The first control plan was more or less an emergency measure (undertaken without adequate advance traffic data) to avoid the "intolerable" situation that had occurred on Memorial Day weekend in 1966. Other plans evolved as more was learned about traffic operation over the system. The basic idea was to relieve the overloaded Golden State Freeway by forcing all of Sierra Highway traffic onto the old highway. Portable barricades were used to close off the connector. On this attempt, however, the old highway could not handle all diverted traffic. This led to the manual metering plan.

Figures 3 and 4 show the manual metering plan. The main objective here was to balance flow between the freeway and the old highway. Police officers stationed on the connector regulated traffic entering the Golden State Freeway. Officers released vehicles in platoons from two lanes every 30 seconds. Initial platoon size was determined from observations made on other occasions. During operation, however, an observer located on the shoulder of the freeway watched traffic flow in the merge and downstream. He instructed officers on when to adjust platoon sizes. The method proved quite sensitive to fluctuations in upstream demand, which turned out to be unexpectedly severe. Originally, 5-minute machine counts were to provide surveillance data. The 5-minute lag proved too great, however.

Minor control was provided as needed at two other critical locations. In all, six police officers were required to operate the plan. Because police officers are in particularly high demand on holiday weekends, to reduce the number required, a plan calling for traffic signal control was developed.

Operation of this plan was essentially the same as with manual control. In this case, however, traffic signals replaced police officers on the connector. The object was to develop a system that could be put into effect by a single officer on routine

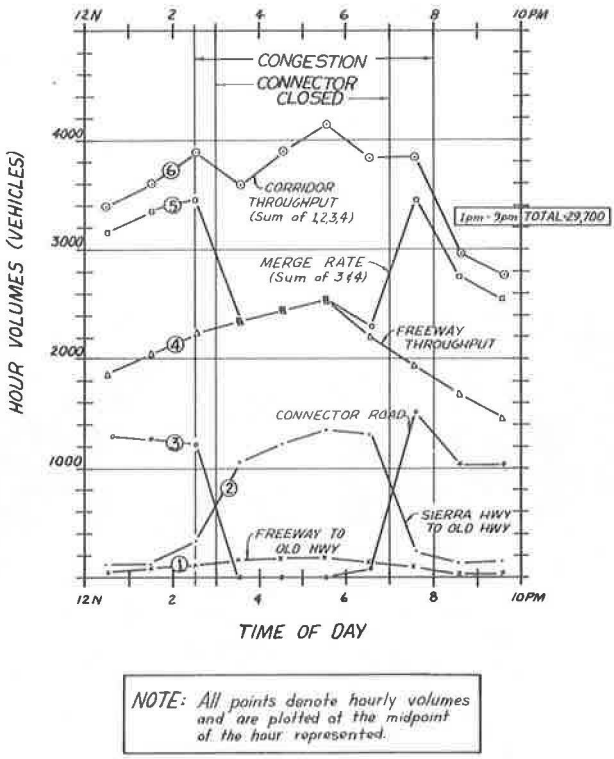

Figure 5. Hourly traffic counts—July 4, 1966.

patrol. Also, since this was the first time entrance control had been used in Los Angeles, experience with signalized control was desired.

OPERATION AND RESULTS

Data were collected on eight weekends. For the sake of brevity, however, only four weekends will be covered here. In general, discussion is organized according to the type of control used. Comparisons of delays are made, but it is emphasized that these are extremely rough estimates. The fact that traffic demands varied so much during the different modes of operation made direct comparisons difficult.

Closed Connector

On July 4, 1966, as a result of "intolerable" congestion on Memorial Day, emergency traffic control measures were taken. Control consisted of closing the connector from Sierra Highway to the southbound Golden State Freeway. The connector was closed for roughly 4 hours from about 3 to 7 p. m. During this time Sierra Highway traffic was diverted to the old highway.

Figure 5 illustrates traffic volumes at various points on the system. The sudden drop in connector volumes at 3 p. m. (curve 3 in Fig. 5) shows when the connector was closed. Reopening is indicated by the jump in connector volumes at 7 p. m. Curve 2 shows the greatly increased flow to the old highway during the period when the connector was closed. The major restriction to this flow was the left turn from Sierra Highway to southbound on the old highway. On this particular occasion, maximum rates of less than 1400 vph were accommodated. This was several hundred vehicles per hour less than demand. Since the old highway provides the only alternate route, excess

demand was forced to store upstream on Sierra Highway. Figure 6a shows the density in the queue that formed. At times this queue extended back 5 miles.

Curve 5 in Figure 5 represents merge rates. Ordinarily this would be the sum of freeway throughput (curve 4) and traffic on the connector (curve 3). While the connector was closed, however, merge volumes and freeway throughput were the same. That connector traffic made up a large portion of the merge volume is demonstrated by the large drop in merge rates at 3 p. m. when the connector was closed.

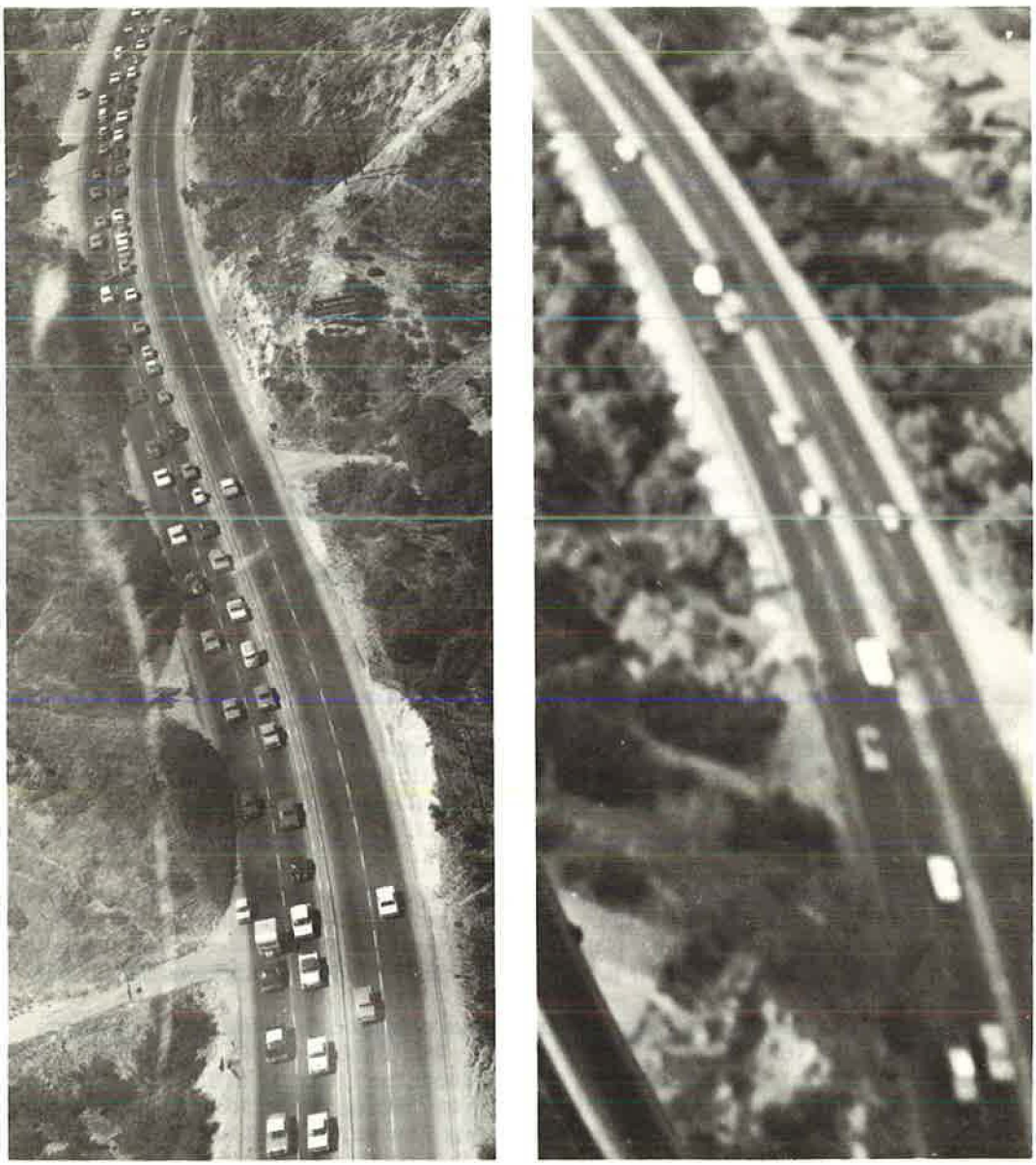

Figure 6. Improved flow: (left) Queue of vehicles backed up on Sierra Highway while the connector was closed (average speed 6 mph); (right) flow during manual control (average speed 40 mph).

The drop in merge rates at 3 p. m. and the subsequent jump at 7 p. m. point out the under-utilization of the freeway during control. Immediately after the connector was opened, merge rates, because of a backlog of demand on Sierra Highway, jumped to 3500 vph. In other words, freeway capacity was at least 1000 vph greater than the average rate of 2400 vph recorded on the freeway while the connector was closed.

During closure, the freeway was able to handle its full demand. In fact, the freeway experienced no congestion at all. Total corridor throughput (curve 6), however, reached a maximum of only 4200 vph. On Sierra Highway, maximum rates totaled about 1400 vph (curve 2 plus curve 3). This is less than the volume that normally would be handled without control.

For the period from 1 to 9 p. m., the total volume was 18,700 vehicles on the freeway approach and 11,000 vehicles on the Sierra Highway approach. The sum of the two (29,700 vehicles) represents full corridor demand because all congestion occurred within this 8-hour period and flow was good at both 1 and 9 p. m. (This was also true for the other days described.)

Total delay on this July 4th was estimated to be 150,000 vehicle-minutes (based on floating car runs, lengths of queue, and duration of congestion). Approximately 7,500 vehicles on Sierra Highway were delayed. This averages to about 20 minutes per vehicle; maximum delays reached 35 to 40 minutes.

Based on subsequent observations on days with and without control, it appears that less total delay would have occurred if the connector had not been closed. Estimates indicate that there would have been about 25,000 vehicle-minutes of delay, and that most of this would have accrued to freeway traffic (i.e., on the high-speed approach). Sierra Highway would have suffered little delay, and congestion on the freeway would have lasted from about 3 to 7 p. m.

In spite of increased overall delay, the fact that the high-speed approach was kept free-flowing is important. It is highly probable that because of this accidents were prevented.

Manual Metering Control

On Labor Day, 1966, control was accomplished by manually metering connector traffic from Sierra Highway to the southbound freeway. Congestion started to develop shortly after 2:30 p. m. Control was begun immediately and continued until demand subsided around 6:30 p. m.; 30-second metering rates were varied constantly between 1200 and 2200 vph. Even so, average flow on the connector over the controlled period remained relatively constant between 1400 and 1500 vph (Fig. 7, curve 3).

The queue, planned for on the connector, developed immediately after control started. The tail of this queue fluctuated between 800 and 1200 ft upstream of the control point. Figure 6b shows the free flow of traffic on upstream Sierra Highway under metering operation. Compare this with the dense queue in Figure 6a—a picture of the same location taken on July 4th.

Signs advising that the old highway provided an alternate to the freeway were displayed. During surges of high demand on Sierra Highway, many drivers diverted voluntarily. This was due, apparently, to the alternate route signs and the lengthening queue on the connector. An officer, provided to direct traffic to the old high-

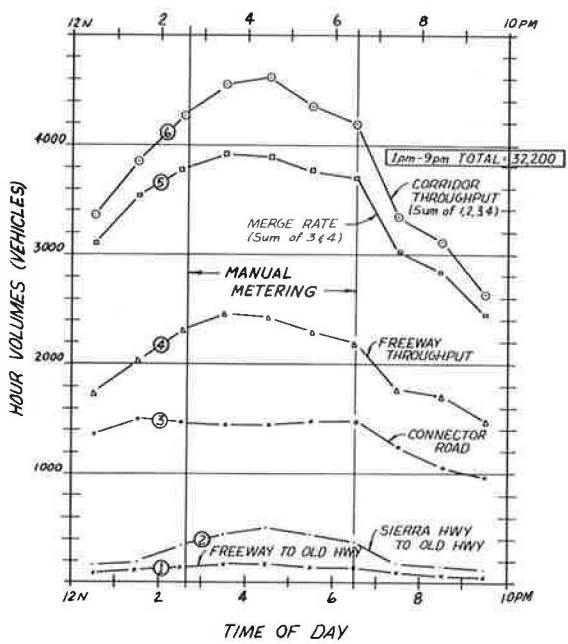

Figure 7. Hourly traffic counts—Labor Day, 1966.

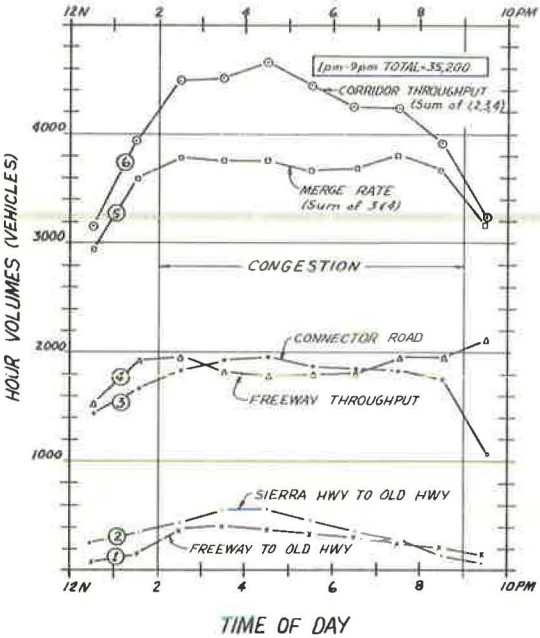

Figure 8. Hourly traffic counts—Thanksgiving Sunday, 1966.

way when the queue extended upstream of the diversion point, was seldom needed. Diversion rates (including those drivers that wanted to use the alternate route) ranged between 400 and 600 vph during the control period (curve 2 in Fig. 7). Thus, Sierra Highway approach volumes averaging around 2000 vph were handled (curve 2 added to curve 3).

The rate of freeway throughput reached a maximum of 2500 vph during control (curve 4). This demand was handled with only minimum reductions in freeway speeds. Fluctuations in demand (5-minute rates ranged from 1600 to 3100 vph) did result in occasional shock waves, but overall freeway delay was negligible.

Total corridor throughput reached 4600 vph (curve 6). This was accomplished with no queues on the freeway and only short queues on the connector. Even so, additional capacity was available on the alternate. Had connector queues extended upstream on Sierra Highway, more vehicles could have been diverted to the old highway and corridor throughput would have been even greater.

Volume for the 8-hr period from 1 to 9 p. m. was 18,400 vehicles on the freeway and 13,800 vehicles on Sierra Highway—a total of 32,200 vehicles. This was 2600 vehicles, or about 9 percent, more than on July 4th. Yet, even with this greater volume, there were insignificant delays to freeway traffic and only about 9000 vehicle-minutes of total delay to Sierra Highway. Maximum delay to individual vehicles on Sierra Highway was less than 2 minutes.

Had there been no control, estimated delays would have been about 170,000 vehicle-minutes. Most of this delay would have been suffered by freeway traffic. Delays to Sierra Highway traffic would have been about the same as with control.

No Control, Heavy Demand

No plans were made to control traffic on Thanksgiving weekend other than to expose signs advising of the alternate route provided by the old highway. Observers had claimed that congestion occurred only during summer months. This proved incorrect. Actually, congestion was greater on Thanksgiving weekend than on any other weekend observed.

Freeway throughput reached an early peak of nearly 2000 vph between 2 and 3 p. m. (Fig. 8, curve 4). Congestion on the freeway began about 2 p. m. A queue extending back 2 miles was observed by 3 p. m., and by 6 p. m. this queue had grown to 10 miles. Evidently, freeway traffic was overpowered by the pressure of increasing demand from Sierra Highway. Merge geometrics give equal advantage to both approaches. In other words, when both approaches were full, each provided roughly half the merge volume. This is borne out in Figure 8 (curves 3 and 4). As a result, freeway throughput (curve 4) dropped slightly during peak Sierra Highway demand. As Sierra Highway demand fell, after 8 p. m., freeway throughput increased, dissipating the 10-mile queue that had formed. It was after 9 p. m., however, before all congestion cleared.

At 3 p. m. only slight congestion existed on the connector (curve 3). The maximum queue observed during the entire afternoon extended back less than ¼ mile. It appeared that many drivers voluntarily diverted to the old highway when it was obvious that there was congestion on the freeway. Voluntary diversion from Sierra Highway reached a high of 600 vph (curve 2).

Voluntary diversion from the freeway also took place. Usually about 200 vph leave the freeway on a normal holiday weekend. However, volumes of 400 vph were recorded on Thanksgiving weekend (curve 1). Unfortunately, not enough freeway users took the old highway early in the peak, and even those that exited to the old highway were trapped in the 10-mile queue. The maximum volume using the old highway reached roughly 1000 vph—600 vph less than volumes recorded on previous occasions when diversion was encouraged by police officers. In other words, the old highway was under-utilized.

Merge rates remained steady at 3700 to 3800 vph throughout the entire 7-hour period of congestion (curve 5). Total corridor throughput reached a peak of 4700 vph from 4 to 5 p. m. and fell gradually as fewer vehicles diverted to the old highway (curve 6).

Volume for the period from 1 to 9 p. m. was 17,400 vehicles on the freeway and 17,800 vehicles on the Sierra Highway—a total of 35,200 vehicles. Estimated congestion totaled some 270,000 vehicle-minutes with individual delays of 30 minutes. Most of this delay was suffered by freeway traffic.

The total corridor volume from 1 to 9 p. m. on Thanksgiving Sunday was 3000 vehicles higher than the comparable volume on Labor Day when control virtually eliminated delay. It appears, however, that had control (manual or signal) been imposed, most of the delay on Thanksgiving Sunday could also have been eliminated. Although corridor ouput was high without control, the alternate route still had additional capacity. Control, of course, would have encouraged greater use of this capacity.

The fact that total corridor throughput was as great as it was can be attributed to the high rate of voluntary diversion to the old highway. This, in turn, can be attributed to (a) driver experience on previous holiday weekends, (b) publicity of previously congested conditions and of the available alternate, (c) signing of the alternate, and (d) perhaps most importantly, the congestion itself.

Traffic Signal Metering Control

Christmas Monday was the first attempt toward automating metering control (Fig. 9). A multi-cycle, variable phase traffic signal had been installed. Cycle selection and

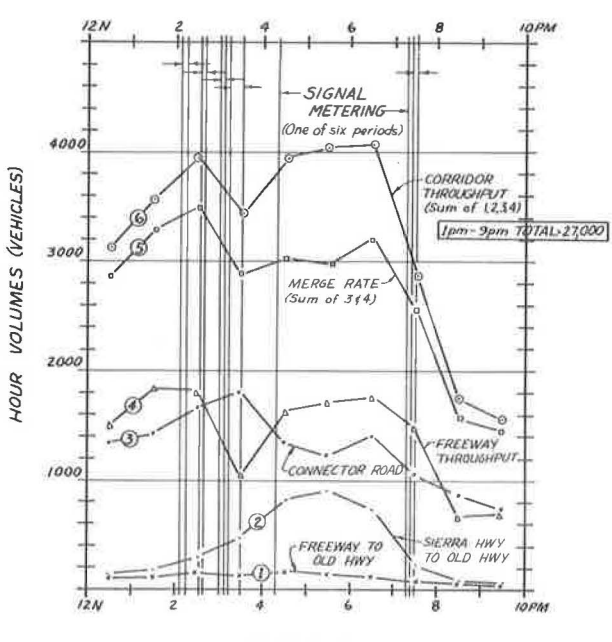

Figure 9. Hourly traffic counts—Christmas Monday, 1966.

phase adjustments were still made manually, however. Surveillance was still accomplished by visual observation of downstream flow supplemented by short manual counts.

Plans were made to operate the signal on four occasions other than Christmas Monday; these were New Year's Monday, the first Sunday of trout season, Memorial Day, and July 4th, 1967. Demand sufficient to require control only occurred on Christmas Monday and the first Sunday of trout season. Only Christmas Monday is discussed here.

Traffic conditions on Christmas Monday were not normal by any means—even for a three-day holiday weekend. Two minor, but disruptive, accidents on the upstream freeway played havoc with freeway demand.

Initiating control involved some hazard because approach speeds on the connector were relatively high. Because of the hazard, start of control was delayed until there was reasonable assurance that continuous control would be required during the remainder of the peak. The resultant criterion was formation of a stable queue (rather than just shock waves) on the freeway at the merge. Had the accident on the freeway been anticipated, signal control could have been operated to prevent queues from forming on the freeway. In fact, to lessen the chance of recurrence of such an incident on subsequent occasions, impending shock waves rather than standing queues became the criterion. This, of course, sacrificed some capacity.

Wide fluctuations in freeway demand on Christmas Monday—almost instantaneous drops and jumps ranging from 2400 vph to less than 1200 vph—led to severe, rapid variation in metering rates. For short periods (2 to 3 minutes) rates on the connector were restricted to as low as 600 vph. This was to allow dissipation of the queues that had formed on the freeway because of accidents upstream.

Five different times during lulls in freeway flow connector traffic was released from direct control. At first this was accomplished by switching the signal to steady green. This, however, seemed to encourage connector traffic to higher speeds, around 50 mph. At these speeds, regaining control was hazardous. Further operation during lulls was on flashing yellow.

Flexibility of signal control was taxed by wide fluctuations in demand. Controller limitations required minimum phase lengths (12 seconds for green-yellow and 9 seconds for red) that delimited the range of settings provided by each of the four cycle lengths. These limits were more restrictive for shorter cycles. For instance, the range of metering rates achieved on the 30-second cycle was 1100 to 2200 vph, while the range on the 60-second cycle was 600 to 2200 vph.

Although the longer cycles permitted greater flexibility, compliance (stopping for the red signal) was not as good. For example, compliance was good on the 30- and 40-second cycles throughout their entire range of settings. On the 50- and 60-second cycles, however, the longer periods of green required to maintain metering rates equivalent to the maximum of shorter cycles allowed vehicles to gain higher speeds. A greater reluctance to comply was observed. In fact, had the longer green phases been sustained, it appeared that loss of metering control might have resulted. Violations were also frequent when a queue did not exist on the connector. It seemed that, at free-flow speeds, drivers simply did not have time to comprehend the strange situation of having to stop for a signal on a freeway-to-freeway connector.

The range of metering rates also affected the time required to negotiate a given length of the connector queue. On Labor Day the maximum time to travel the length of the connector was about 2 minutes. On Christmas Monday, however, a much denser and slower moving queue developed. This queue required a maximum of 5 minutes to travel the length of the connector. During heaviest demand the queue extended upstream of the exit to the alternate route.

Also of interest were the platoons released from the signal. Their size varied in proportion to the length of the green-yellow phase. Between the minimum and maximum phase lengths of 12 and 51 seconds, the platoon size ranged from 9 to 36 vehicles. Manual metering on Labor Day resulted in fairly well-spaced platoons. Those released from the signal, however, were much more closely spaced. In each case, platoons with more than 10 vehicles tended to disrupt freeway traffic. However, groups of up to 20 vehicles were able to merge with relative ease. Platoons of greater than 20 vehicles were impractical because of problems in merging, compliance, and control.

All in all, Christmas Monday provided a true test of the flexibility of traffic signal control. Volume for the 8-hour period from 1 to 9 p. m. was 13,100 vehicles on the freeway and 13,900 vehicles on Sierra Highway—a total of 27,000 vehicles. This total was less than the total on July 4th. Even so, Sierra Highway demands were greater on this occasion.

Good estimates of total delay are not available for Christmas Monday. Generally, though, the freeway was kept free-flowing. On Sierra Highway, however, metering rates were kept quite low at times (for reasons noted) and diversion to the old highway, while high, was not as efficient as it could have been. For roughly an hour this resulted in significant delays (up to 10 minutes) to Sierra Highway traffic.

Another factor contributing to Christmas Monday problems was an unusually low merge capacity. Actually, merge capacity is limited by what the downstream section can absorb. On this day the downstream section was not working well at all. In spite of the various problems, it appeared that control was successful and that the relatively large diversion to the old highway allowed better overall operation and reduced travel time. Without this diversion, the large queues on the freeway (caused by accidents) could not have been dissipated and extremely large delays would have occurred.

Increased Capacity Conditions

The interim widening project was completed just prior to the 1967 Labor Day weekend. Operation was observed, and the additional capacity eliminated all problems. Continuous counts were not made, but short (3-minute) counts made during the peak indicated the merge rate varied between 4000 and 4600 vph. Capacity of the merge and downstream section is now about 5400 vph. Use of the Alternate route varied between 300 and 400 vph. Total corridor demands were about 4600 to 4700 vph, which are the same as those occurring during the 1966 Labor Day weekend.

On Thanksgiving weekend (1967) demands were extremely high, with corridor outputs (based on short counts) reaching 5100 to 5300 vph, including approximately 4800 vph on the freeway. Traffic demands on the freeway approach were so high that there was congestion on the two-lane section upstream of the exit to the old highway. Even so, the corridor was able to handle, reasonably well, all traffic that could reach the section. Control would not have improved operation.

SUMMARY AND CONCLUSIONS

Higher than normal traffic volumes occurred at the merge between Sierra Highway and the southbound Golden State Freeway on eight occasions between July 4, 1966, and July 4, 1967. During that time, two basic approaches were used to regulate merging traffic. The first approach was to completely close off the entrance to the freeway; the second approach concentrated on regulating, or metering, entrance traffic.

Steps toward automated surveillance and metering control have not been taken because an interim widening project now provides more than enough capacity at the merge. Consequently, conclusions drawn here are based on metering rates determined by direct visual surveillance and accomplished by manual regulation of traffic or by traffic signal control, whichever applied.

In comparing the various control plans it was found that closing the connector resulted in under-use of the freeway at the expense of Sierra Highway, which backed up 5 miles. It took as much as 40 minutes to traverse this queue, and total delay was about 150,000 vehicle-minutes.

Getting full use of freeway capacity required that a certain amount of traffic be allowed onto the freeway via the connector. Direct control by manual metering resulted in an average merge rate of from 3600 to 3900 vph during the metering period; 5-minute rates on the uncontrolled leg ranged from 1600 to 3100 vph.

The most unique feature of the plan was the magnitude of connector rates allowed onto the freeway; 30-second rates were varied between 1200 and 2200 vph. Achieving these rates required utilization of both connector lanes. It was also necessary to release vehicles in platoons, compared with the one-at-a-time operation usually used. Metered platoons contained 10 to 18 vehicles, depending on available freeway capacity.

Manual metering control resulted in negligible delay to freeway traffic. Individual Sierra Highway delays were less than 2 minutes, vs the 40-minute delays on July 4th. Total delay was about 9000 vehicle-minutes. It only required a diversion of 400 to 600 vph to accomplish this.

A standard traffic signal provided metering control that was less flexible but comparable to manual metering control; 30-, 40-, 50-, and 60-second cycles with 12-second minimum green-yellow and 9-second minimum red phases were used. Cycle-to-cycle rates for signal metering were also varied from 1200 to 2200 vph according to available capacity.

Generally, drivers obeyed signals on 30- and 40-second cycles. It appeared, however, that higher speeds generated from relatively long green phases associated with some 50- and 60-second cycles made compliance more difficult. This difficulty was evidenced in that a number of drivers simply ignored the signal.

Analysis and evaluation of data collected on the eight occasions of heavy congestion provide results from which the following conclusions are drawn.

1. Marginal nature of ramp control: (a) Under normal conditions, diverting just a few vehicles (often as few as 100 to 200 vph) accomplishes great improvements in freeway operation; (b) heavy surges in traffic—following removal of accident vehicles from the traveled way, for example—may overwhelm metering operation.

2. Ramp closing: Closing a high-volume entrance may result in a partially empty freeway. This method should only be considered when the ramp volume is less than the excess demand downstream from the entrance, and/or the alternate routes have adequate capacity to absorb diverted traffic.

3. Variable control: (a) Variable control allows adjustment of ramp volumes to fill excess freeway capacity; (b) variable control can be sufficiently sensitive to smooth normal fluctuations in freeway flow; (c) variable control may be accomplished either manually or by using traffic signals.

4. Manual control: (a) Manual control allows precise adjustment of flow rates; (b) manual control spaces vehicles more evenly in merging platoons, reducing merge friction.

5. Signal control: (a) Cycles of 30 to 40 seconds result in good signal compliance, tolerable platoon size (9 to 20 vehicles), and less flexible metering rates (1100 to 1800 vph) than longer cycles; (b) cycles of 50 to 60 seconds result in signals being ignored (because of the higher speeds generated), intolerable platoon size (up to 36 vehicles), and more flexible metering rates (600 to 2200 vph) than shorter cycles; (c) traffic approaching the control signal should be slowed to less than 40 mph (by advance warning lights for example) prior to and during control; (d) a variable cycle having a fixed green-yellow phase of 12 seconds, and a variable red phase of 48 seconds maximum and 8 seconds minimum is recommended—this would allow metering rates ranging from 600 to 1800 vph while retaining the optimum 10-vehicle platoon for two-lane entrances.

6. Surveillance: Speeds and densities in the merge and immediately downstream provide the best indication of when to adjust metering rates.

7. Bypass routes: (a) If bypass capacity is not adequate to handle diverted traffic, bigger problems may be created than the one solved; (b) a number of drivers bypass congestion of their own accord when they know of alternate routes; (c) ideally, drivers should be persuaded to take an alternate route before congestion develops (however, this is against human nature).

8. Merge gaps: Sufficient gaps exist in freeway flow at 45 mph to allow platoons of 10 or fewer vehicles to merge with little friction. Merge design must be good, however.

9. Safety: (a) Metering improves safety by either stabilizing or eliminating queues; (b) metering high-speed, high-volume traffic is potentially hazardous and requires thoroughly indoctrinated personnel to supervise and to perform metering activities.

10. Costs and benefits: (a) Controlling ramps is relatively inexpensive, especially when compared with the cost of increasing capacity by widening; (b) typically, on this project, time savings exceeded 150,000 vehicle-minutes per day of control.

In general, merge control when properly applied provides an inexpensive and effective means of increasing the amount and quality of traffic flow. Furthermore, merge

control reduces overall delay by taking advantage of all available corridor capacity. Much research remains to be done toward application, but as knowledge continues to grow and more advanced techniques are developed, it would seem that merge control will eventually lead to fuller and more efficient utilization of the existing street and freeway system.

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This report is condensed to meet publication requirements. A more detailed report may be obtained from the Freeway Operation Department, California Division of Highways, 120 S. Spring Street, Los Angeles, California 90012.