enforcement perspective, however, is a resource that is available to the transportation planning community, not only for its safety expertise, but for improving the effectiveness and efficiency of the transportation system and ensuring that the goals and objectives for individual projects are met. Awareness of that perspective and using it for the public good are the sole purpose and intent of TRANSPORTS. The transportation planning and law enforcement communities must share the responsibility for bringing that perspective into focus.

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Enforcement of TSM Projects

JOHN W. BILLHEIMER

Transportation system management (TSM) strategies introduced on California freeways in recent years have included ramp metering, preferential lanes for high-occupancy vehicles, and bypass lanes for buses and carpools at metered ramps. Several factors have frustrated efforts to enforce the traffic laws that accompany these strategies; these include personnel limitations, enforcement priorities, public hostility, confusion, and physical constraints imposed by the geometry and design of specific projects. As a consequence, violations have increased on several projects. This paper covers the first six months of an ongoing two-year study designed to measure and evaluate the effect of different enforcement options, engineering features, and educational programs on violation rates for various TSM freeway strategies and to trace the resulting impact of these violation rates on safety, freeway performance, and public attitudes. During this six-month period, statistics were assembled to describe violation rates, enforcement levels, and operating performance on current and past California projects; drivers were surveyed; and different levels and combinations of routine and special enforcement activities were tested on a variety of TSM projects. Violation rates were measured before, during, and after the assignment of highway patrol officers to enforce specific projects. This paper documents current violation rates, sketches profiles of violator behavior prior to special enforcement activities, outlines the preliminary results of the first wave of special enforcement, and documents the results of surveys designed to test the attitudes of drivers toward violators, enforcement, and the TSM projects themselves.

Adequate control of violation rates on preferential lanes for high-occupancy vehicles (HOVs) and other transportation system management (TSM) projects requires an effective mixture of enforcement, engineering design changes, and public education. Although past experience with similar projects has given the California State Department of Transportation (Caltrans) and the California Highway Patrol (CHP) a number of insights regarding the potential effectiveness of different enforcement strategies, engineering changes, and education programs, this experience has not been documented with the quantitative precision necessary to identify the appropriate levels and mixture of these factors needed to obtain adequate motorist compliance. The purpose of the study described in this paper is to provide a detailed, quantitative, and objective assessment of the effect of different enforcement options, engineering features, and educational programs on violation rates for various TSM freeway strategies and to trace the resulting impact of these violation rates on safety, freeway performance, and public attitudes.

STUDY OVERVIEW

As a first step in accomplishing the study objectives, SYSTAN Inc., developed a detailed study design (1) that itemizes project objectives, specifies measures of effectiveness, outlines procedures for data collection and analysis, and provides a structured statistical framework for assessing the effectiveness of different enforcement options, engineering features, and educational programs.

Projects to be Evaluated

Mainline HOV Lanes

In the case of mainline HOV lanes, the different engineering options to be evaluated are limited to the major projects currently in place on California freeways. These projects include the nonseparated right-of-way on Marin RT-101 north of the San Francisco Bay Area; the preferential lane of Interstate 580 in Alameda County, which is separated from regular traffic by a buffer lane; and the 11-mile San Bernardino Busway east of Los Angeles, where the preferential lane is separated from general traffic by concrete barriers on the western end of the freeway and by a buffer shoulder and pylons on the easternmost 7 miles of the project. Detailed descriptions of each of these projects may be found in the study design (1).

Ramp Bypass Lanes

The full range of characteristics of bypass lanes represented on California freeway ramps are being tested to determine their impact on enforcement and violations. More than 130 ramp bypass lanes currently provide preferential access to carpoolers and buses that use Los Angeles freeways; San Diego has 7 such lanes, 3 of which have been installed on freeway-to-freeway connectors. Existing bypass lanes have been classified in groups according to a number of important geometric features, design choices, and performance characteristics, including the visibility of the enforcing officer and the current violation rate. In developing a sampling framework, three levels of officer visibility and ramp violation rates were defined:

Officer visibility--not visible, queue-dependent, and visible.

Ramp violation rates--high, more than 12 percent; medium, 12-6.5 percent; and low, less than 6.5 percent.

The visibility of the enforcing officer is rated from the driver's point of view as he or she enters the ramp. If the enforcing officer can be seen as soon as the driver is on the ramp, enforcement is classified as visible; if the officer cannot be seen until a violator passes the meter, enforcement is classified as not visible; if the visibility of the officer depends on the position of the driver in the queue on the ramp, enforcement is classified as queue-dependent. In addition to ramp violation rates and officer visibility, other classification

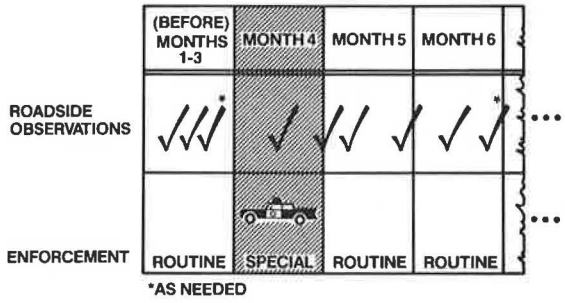
concerns include the characteristics of the area served by the ramp (i.e., residential or industrial), ramp geometry (i.e., diamond or loop), availability of a refuge area for enforcement, length of time a ramp has been operating, relative percentage of regular users, freeway performance in the vicinity of the ramp, and existence of any special engineering problems (i.e., turning lanes that can trap single-occupant vehicles in the carpool lanes).

Data Collection

A typical pattern for field observations for a specific TSM project is shown in Figure 1. This pattern calls for observation of violation rates for 2 or 3 days prior to the introduction of special enforcement activities, followed by as many as five observations during the 2 months following these activities. This series of observations focuses attention on the behavior of the motorist after special enforcement activities have ceased. The need for the last observation in each sequence is determined by applying prespecified testing procedures to earlier observations in the sequence (1). Experiments with different enforcement levels have been scheduled sequentially over a period of nearly 2 years, so that the results of ongoing analysis and the observations of enforcement personnel can be used to direct future testing.

This paper summarizes the results observed during the first six months of the ongoing 2-year study. During this 6-month period, statistics were assembled that describe violation rates, enforcement levels, and operating performance on current and past TSM projects in California; drivers were surveyed; and an initial wave of enforcement was launched in which different levels and combinations of routine and special enforcement activities were tested on a variety of TSM projects. Violation rates were measured before, during, and after the assignment of CHP officers to enforce specific HOV lanes and metered freeway ramps. This paper documents current violation rates, sketches a profile of violator behavior on each TSM project prior to special enforcement activities, outlines the preliminary results of the first wave of special enforcement, and documents the results of surveys designed to test the attitudes of drivers toward violators, enforcement, and the TSM projects themselves. Additional details on each of these topics may be found in the first interim report on the project (2).

Figure 1. Typical pattern of field observations.



VIOLATION CHARACTERISTICS

Table 1 summarizes violation statistics on key California TSM projects during the study implementation phase, prior to the introduction of any special enforcement programs. This table shows that the percentage of vehicles that used California mainline HOV lanes illegally during the preenforcement phase of the study ranged from 8.8 percent on the San Bernardino Busway to 30.5 percent on the controversial Alameda I-580 diamond lanes. Occupancy violations on the shoulder-separated right-of-way of the San Bernardino Busway averaged 7.3 percent of all vehicles in the lane during the morning peak and 10.5 percent of all vehicles in the afternoon. These violation rates were lower still (estimated at 3 to 4 percent) on the portion of the busway where a physical barrier makes lane-switching impossible. Although violation rates on the San Bernardino Busway and Alameda-580 had not increased appreciably over prior measurements, the 21.5 percent violation rates recorded on Marin-101 represented an increase over the violation rates of 5-15 percent reported roughly 1 year earlier.

The average lane violation rate for a sampling of 39 metered ramps that have HOV bypass lanes in the Los Angeles area was 37.7 percent, which is appreciably higher than the comparable violation rate on any mainline HOV project in California. This rate appears to be increasing on most ramps, and bypass lanes that have been operational for several years have significantly higher ramp violation rates than do newly opened lanes. The relative number of vehicles that use bypass lanes illegally ranged from a low of 13 percent to over two-thirds of all vehicles in the bypass lane. (In terms of the total number of vehicles on the ramp itself, these percentages range from a low ramp violation rate of 2.4 percent to a high rate of 39 percent.)

Table 1. TSM project violation rates and historical enforcement levels.

Type of Roadway	Project	Violation Data: Lane Violation Rate (%)	Violation Data: Ramp or Freeway Violation Rate (%)	Enforcement Data: Past Citation Rates	Enforcement Data: Apprehension Rate (%)	Average HOV Time Savings (min during peak hour)
Mainline HOV lanes						
Nonseparated lanes	Marin-101	21.5		11.6/day	2.6	Negligible[a]
	Santa Monica[b]	15.1	1.0	55/day		5-6
Separated lanes	Alameda I-580	30.5		2.5/day	0.8	Negligible[a]
	San Bernardino	8.8		10.8/day	3.3	5-7
Metered ramps						
Without bypass lanes		3.8[c]	3.8[c]	NA	NA	NA
With bypass lane	Los Angeles	37.7	12.8	0.27/ramp/day	0.18	1.3
	San Diego	19.5	3.0	0.07/ramp/day	0.24	0.4
Exclusive HOV bridge lane	San Francisco-Oakland Bay Bridge	5.4	0.7	2.4/day	1.1	4-5

[a] Average time savings is under 20 s. [b] Project discontinued. [c] Meter violation rate.

HOV lane violation rates were found to be considerably lower (averaging 19.5 percent on a sampling of seven HOV bypass lanes) in San Diego, where the peak traffic periods are shorter, meters are traffic-responsive, and the HOV lanes themselves are meter-controlled. The lowest lane violation rate recorded on any HOV project in California was the 5.4 percent violation rate on the San Francisco-Oakland Bay Bridge, which consistently offers carpoolers substantial time savings of 4-5 min, in addition to a toll-free trip across the San Francisco Bay.

The number of drivers who ignore meter restrictions by running the red light is relatively low, and is not considered to be a major problem by either Caltrans or the CHP, particularly because such violations tend to occur when traffic volumes are low and ramp queues are short or nonexistent. In Los Angeles, the level of meter violations is significantly higher on ramps without bypass lanes than on ramps with such lanes (3.8 versus 0.99 percent of all vehicles on the ramp), as the bypass lane itself provides a convenient pathway for those potential violators who might otherwise simply run the red light.

VIOLATOR BEHAVIOR

Violations by Time of Day

On Marin-101, violations tend to cluster on the fringes of the morning and evening operating hours. A high proportion occur just after restrictions come into play at 6:00 a.m., again at 4:00 p.m., and just before restrictions are removed at 9:00 a.m. and 7:00 p.m. (see Figure 2). A similar phenomenon was observed during morning and evening operating hours on the ill-fated Santa Monica Freeway diamond lanes (3). In the case of Alameda-580, preferential lane restrictions begin officially on Monday at 6:00 a.m. and are legally in force until Friday at 6:00 p.m. However, an unusually high proportion of violations occur between 6:00 p.m. and 7:00 p.m. every weekday (see Figure 3), which suggests that a large number of drivers wrongly interpret the operating hours to be 6:00 a.m. to 6:00 p.m., Monday through Friday. In this case, then, a significant proportion of peak-period violations could presumably be eliminated by redesigning either the signs or the operating hours.

On the separated right-of-way of the San Bernardino Busway, violations during the evening peak coincide with peak traffic volumes, but violations during the morning peak are concentrated during the first hour of lane operations, when darkness and CHP shift changes combine to create a lull in enforcement activities. Violations on Los Angeles bypass ramps also tend to be slightly higher at the beginning of the morning metering period and at the end of the evening period, when darkness makes the lanes difficult to observe and enforce. Ramp violation rates in San Diego tend to coincide with periods of heavy morning traffic and peak on the hour, just before 7:00 a.m. and just before 8:00 a.m.

Impacts of Delays

Little correlation was found between ramp violation rates and the time saved by bypassing the queue in the metered lane (see Figure 4). Although ramp violation rates increase slightly with the delay in the queue (rising to an average of 19 percent for delays of 2 min), the average violation rate recorded for delays under 20 s was a still-formidable 12 percent. The majority of the delays recorded by roadside observers were under 20 s.

Figure 2. Mean violation rate by time of day (Marin).

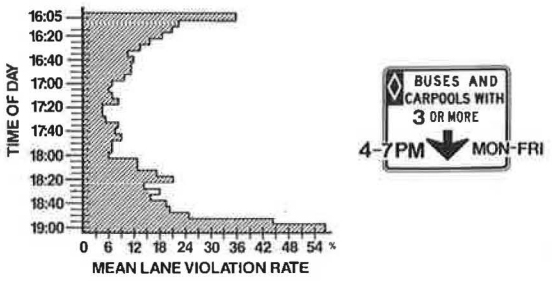


Figure 3. Mean violation rate by time of day (Alameda).

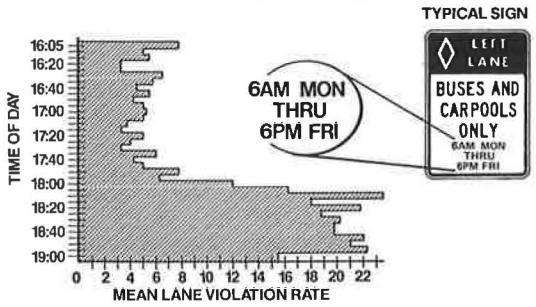
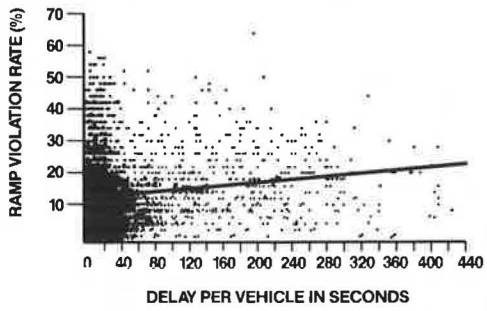


Figure 4. Ramp violation rate versus delay.



Observers reported that some single-occupant vehicles in Los Angeles used the HOV lane illegally even when the non-HOV lane had no cars at all. Drivers of those vehicles apparently simply wanted to avoid stopping for the signal, and felt that running a red signal light was a more serious violation (or potentially more hazardous to their health) than was illegal use of a HOV lane.

Although violation rates varied widely and unpredictably with ramp conditions, some evidence suggests that drivers' perceptions of delay stem not so much from the queue length as from the meter rate. Given the same delay, drivers appear more willing to stay in a long queue that is moving relatively fast than in a short queue that is moving very slowly because of a long meter cycle time. Figure 5 plots the mean ramp violation rate as a function of the meter cycle time for a sampling of 29 Los Angeles ramps.

Repeat Violations

Relatively few instances of repeat violations were observed on any TSM project. Preliminary findings suggest that HOV lane violation rates tend to reflect the actions of a large number of drivers who

Figure 5. Impact of meter rate on ramp violations.

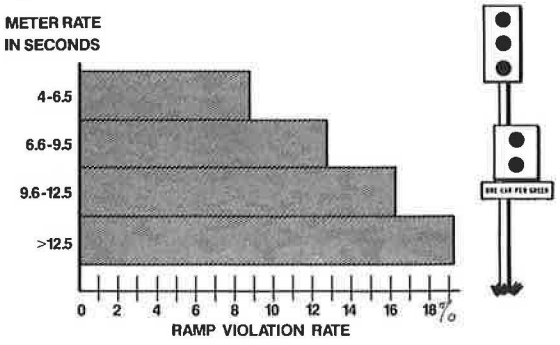
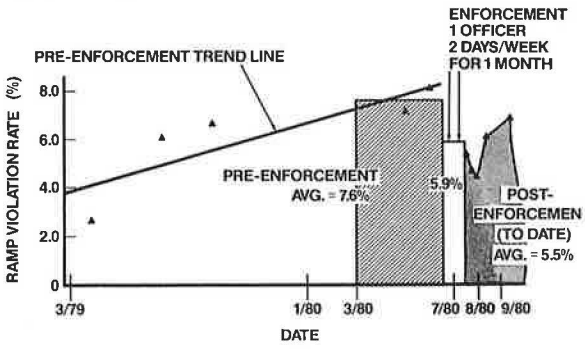


Figure 6. Ramp violation rate over time for Orangethorpe ramp in the morning.



transgress at infrequent intervals, rather than the day-to-day actions of a small group of repeaters. This indication is supported by the responses to numerous survey questions, which suggest that observed violators are not markedly different from ordinary drivers.

ENFORCEMENT IMPACTS

Past Enforcement Levels

In the past, the CHP has applied a policy of relatively low-priority, routine enforcement to ramp bypass lanes. Available personnel have enforced the lane restrictions in addition to performing regular patrol duties. As the number of bypass lanes in Los Angeles has exceeded 130, however, the supply of bypass lanes in some CHP command areas has actually outnumbered the supply of officers available for all patrol duties during the peak traffic periods. As a result, a ramp-by-ramp survey of seven command areas in Los Angeles and two in San Diego showed that the average number of occupancy citations issued per bypass lane was slightly more than one per week at the start of this study.

Past citation rates on mainline HOV lanes have been considerably higher than those for bypass ramps, and range from a low of 4 tickets/weekday on Alameda-580 to 14 tickets/weekday on the San Bernardino Busway. Additional officers are routinely assigned to patrol the freeways adjacent to the mainline HOV lanes in order to enforce the preferential lane restrictions.

Special Ramp Enforcement Activities

The first wave of special enforcement activities on ramp bypass lanes in Los Angeles and San Diego was scheduled over the 4-month period between June and September 1980. Officers were assigned to particular projects for a specific number of days each week for periods of 1-3 months. These special assignments were applied randomly and interspersed with periods of routine enforcement.

Enforcement tactics employed on the ramp bypass lanes varied from officer to officer and ramp to ramp. The most popular and effective tactic on ramps with ample refuge areas entailed parking the patrol car or motorcycle beyond the meter and standing in place in the refuge area to wave violators over. On ramps that have scanty refuge areas, officers positioned themselves and their vehicles either ahead of the meter or behind it, and pursued suspected violators along the freeway until they could be pulled over. Since this tactic leaves the officer at some distance from the ramp being enforced, it is less efficient than in-place enforcement, both in producing citations and in providing an example to other ramp users.

Typical Violation Patterns

The interim report (2) contains detailed accounts of observed violation rates before, during, and after the first wave of special enforcement activities on each sample ramp in Los Angeles and San Diego. Figure 6 charts the typical behavior of ramp violation rates over this period, by using as an example the Orangethorpe ramp leading to westbound CA-91 in Orange County. This graph reflects the general tendencies observed on most Los Angeles ramps. Historical counts collected prior to the current project are typically lower than the preenforcement counts collected in May and June 1980, which indicate a general trend of increasing violations. The average preenforcement ramp violation rate was 7.6 percent, which reflects an average of 121 violations/peak period. The violation rate dips to 5.9 percent during the special enforcement period, which covered a one-month period between mid-June and mid-July. During this period a motorcycle officer was stationed at the head of the Orangethorpe ramp 2 days each week for the entire period of meter operation. The officer issued 59 citations during this period, for an average of 8.4 on each day of special enforcement, or 3.0 on each weekday during the month. This citation rate was far higher than the average of 0.23/ramp/day turned in on all ramps within the cognizant CHP area during the early months of 1980.

Following the one-month enforcement period, the violation rate dipped still further and reached a low of 4.3 percent (73 violations) during the third week following enforcement. The violation rate then began to climb and rose to 6.1 percent four weeks after the special enforcement period eased and 6.7 percent eight weeks following enforcement. Statistical tests showed that the difference between the four week level and the preenforcement level was not statistically significant (at the 0.05 level), so a conservative assumption was made that the impact of special enforcement was no longer felt at this point.

Different Enforcement Levels

During the first wave of ramp enforcement activities, several different levels of special enforcement were tested on ramps that have different geometric characteristics and violation histories. At this time broad conclusions about the overall impact of this activity can be drawn, but data are still being assembled regarding the details of citation rates and enforcement tactics. Figures 7 through 10 chart the broad impacts of four different levels of special enforcement:

Figure 7. Composite enforcement impacts for eight-ramp sample.

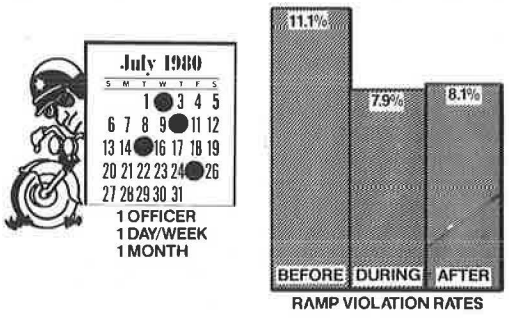


Figure 8. Composite enforcement impacts for five-ramp sample.

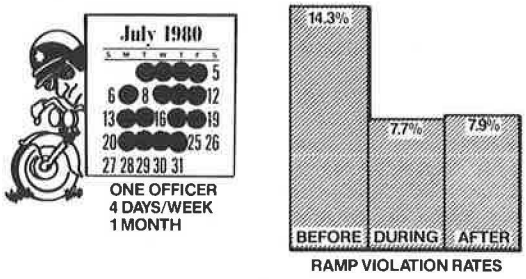


Figure 9. Composite enforcement impacts for four-ramp sample.

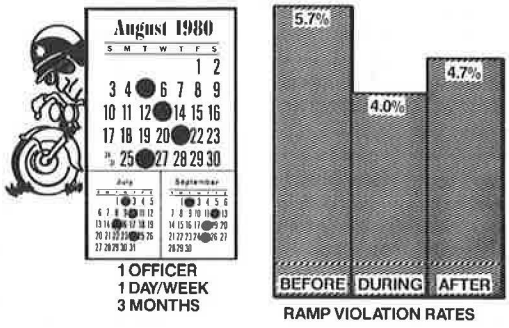
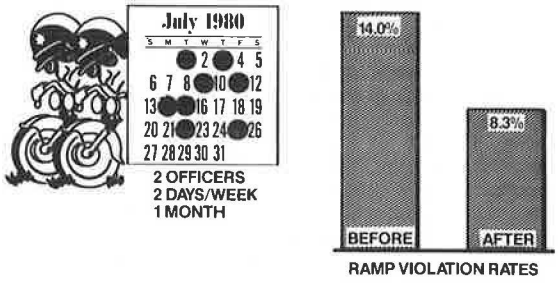


Figure 10. Typical enforcement impacts for one-ramp sample.



1. One officer, 1 day/week for 1 month (Figure 7);
2. One officer, 4 days/week for 1 month (Figure 8);
3. One officer, 1 day/week for 3 months (Figure 9); and
4. Two officers, 2 days/week for 1 month (Figure 10).

The results of these enforcement levels are plotted for composite ramps constructed by averaging the violation rates on appropriate ramps before, during, and after the indicated levels of enforcement were applied. This method of aggregating results contains several inherent statistical flaws:

1. All postenforcement measurements are averaged together, which masks upward trends as the impact of enforcement wears off. For this reason, the after percentages in Figures 7-10 actually represent a conservative upper bound on the impact of enforcement.
2. The results are biased by the nature of the ramps selected to receive each level of enforcement. Ramps that have a history of low-violation rates tended to receive lower levels of enforcement and did not respond as dramatically to these levels as did ramps that had a history of higher enforcement levels. The heavy presence of these low-violation ramps in the composite statistics for low levels of enforcement activity biases these results.
3. The composites depicted in Figures 7-10 tend to obscure the results obtained on individual ramps, which will be the focal point of future analyses. The ramp-by-ramp response of violators to special enforcement activities can be found in the interim report (2).

In spite of all these drawbacks, the composite results depicted in Figures 7-10 summarize the central outcome of the first wave of enforcement activities with a minimum amount of distortion. That is, even the lowest level of special enforcement activity (one officer, 1 day/week, for 1 month) reduced ramp violation rates significantly. Moreover, violation rates tended to remain low for as long as four to eight weeks following the cessation of special enforcement activities. Extension of the period of special enforcement from 1 to 3 months did not produce a corresponding reduction in ramp violations, which suggests that the marginal impact of special enforcement activity diminishes with time. Future study activities will further explore this relationship.

Because of the longer time spans involved, the impacts of 3-month periods of special enforcement were not available for analysis at this time.

Effect of Past Violation Patterns

Special enforcement appeared to be most effective on ramps where violation rates were previously medium or high (see Table 2).

On ramps where ramp violation rates were already low (i.e., under 6.5 percent), special enforcement seems to have less impact in reducing occupancy violations further, and violation rates returned to preenforcement conditions much faster. This suggests that there is a practical limit on the reductions that can be brought about by enforcement, and, consequently, special enforcement efforts should not be expended in an attempt to make tolerably low violation rates lower still.

Enforcement on Newly Opened Ramps

Start-up enforcement strategies were tested by selecting matched pairs of newly opened ramp bypass lanes similar in geometric configuration and enforcement visibility, initiating special enforcement activities on one ramp of each pair, and restricting the other ramp to low-priority routine enforcement.

After one month of special enforcement activities, all ramps that received special enforcement had significantly lower violation rates than did their opposite numbers. In general, the heavier the ramp enforcement activity, the wider the spread

Table 2. Effect of enforcement on ramps that have different historical violation rates.

Preenforcement Violation Category	Ramp Violation Rates				
	Avg Preenforcement Level	Avg Level During Enforcement	Drop (%)	Avg Post-enforcement Level	Drop (%)
High violations, 14 ramps	19.9	12.8	35.7	13.2	33.7
Medium violations, 10 ramps	9.0	5.9	34.4	5.7	36.7
Low violations, 9 ramps	3.8	3.3	13.2	2.9	23.7

Table 3. Lane violation rates before, during, and after enforcement for mainline HOV lanes.

Item	Marin-101		Alameda-580		San Bernardino Busway	
	Morning	Evening	Morning	Evening	Morning	Evening
No. of violations						
Before enforcement	14.1	29.0	28.5	32.7	7.3	10.5
During enforcement	9.9	17.4	25.9	21.3	6.0	7.0
After enforcement						
Week 1	9.7	21.2	11.5	19.8	5.4	6.5
Week 2	9.9	23.6	25.0	20.5	4.1	5.4
Weeks 3 and 4	18.2		24.8	19.0	3.7	4.8
Week 5	19.1	25.2	16.4	21.1	2.6	4.7
Weeks 7 and 8		33.3		25.2		
No. of additional officers	0	2	2	2	6	4
Days per week		4	2	3	2	2
No. of weeks		2	2	2	2	2

between violation rates on the enforced ramps and their unenforced counterparts. Violation rates on the unenforced ramps rose relatively rapidly and exceeded 15 percent within 6 weeks of the opening date on two of four control ramps. This rapid rise suggests that Los Angeles drivers who use the new lanes have had enough past experience with bypass lanes in other areas to have formed opinions regarding the relatively low levels of CHP enforcement and the correspondingly low probability of violator apprehension.

Special Mainline Enforcement Activities

The first wave of special enforcement activities took place on mainline HOV lanes early in May 1980. Periods of special enforcement were shortened to 2 weeks so that postenforcement measurements could be made in advance of summer vacation. Between two and four additional officers were assigned to each project for 2-4 days/week during each 2-week enforcement period.

Preferential lane restrictions on Marin-101 are generally enforced by using motorcycles because of the lack of a median lane and the limited amount of shoulder space. Enforcement officers need to guide violators across three lanes of traffic to a narrow 8-ft shoulder. During the winter rains, when motorcycle use is hazardous, a patrol car is parked in a highly visible position on the freeway shoulder to discourage violators, slow down traffic, and respond to accident calls. In recent months, preferential lane enforcement activities have been concentrated during the evening peak. These evening activities have evidently had a chastening impact on morning drivers as well, since the average lane violation rate is lower in the morning than in the evening (14.1 percent during the morning peak versus 29.0 percent during the evening peak).

Alameda-580 is most often enforced by patrol cars. Officers on Alameda-580 pull violators over to a fairly wide shoulder that has a dirt median. The San Bernardino Busway is enforced by a combination of patrol cars and motorcycles. Occupancy violations are detected by assuming a position on the buffer lane that separates the eastern section of the busway from the general flow of traffic, and citations are issued either on the shoulder or on the buffer lane itself. Enforcement of the physically separated western section of the busway is minimal because violation rates are low, and the limited access makes it difficult to patrol efficiently.

Table 3 lists lane violation rates before, during, and after enforcement for the three mainline HOV lanes. On each project, the special enforcement activity had a significant impact in reducing violation rates. Projects differed primarily in the residual impacts of enforcement. Violation rates on both Alameda-580 and the San Bernardino Busway remained lower than preenforcement levels for at least 8 weeks, until the summer vacation period began. Marin-101 experienced large reductions during both the morning and evening peak periods, even though special enforcement activities were only scheduled during the evening commute hours. The percentage reduction, however, was smaller in the morning, and conditions returned to normal faster. The relative decline in violation rates was not so great on the San Bernardino Busway as on the other two mainline lanes, primarily because the busway violations were relatively low to begin with.

DRIVER ATTITUDES

Before special enforcement activities were initiated, surveys were mailed to a sample of single drivers, carpoolers, and carpool-lane violators on three mainline HOV lanes, six ramp bypass lanes in Los Angeles, and two bypass lanes on freeway-to-freeway connectors in San Diego.

The populations surveyed on each project were contacted by sampling the license plates of vehicles that use the carpool lane and adjacent lanes, by using department of motor vehicles records to obtain the addresses of vehicle owners, and then mailing the surveys to the owners' homes. To ensure the anonymnity of respondents, no attempt was made to link the surveys to a particular driver. Surveys were printed separately for each project and color-coded so that the responses of violators, carpoolers, and general drivers could be analyzed independently. Copies of the basic survey form and a summary of the response rate from each project group

can be found elsewhere (2). The overall response rate for all projects averaged 22.5 percent; the highest response rate was from general drivers (24.4 percent), followed by carpoolers (20.9 percent), and violators (18.8 percent).

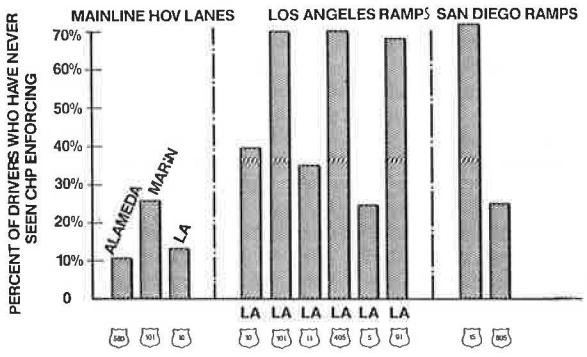
Findings

In general, the tabulated survey responses seem to indicate that, although the differences among violators, carpoolers, and general users on a particular project are few and generally predictable, major differences separate the attitudes and perceptions of users of individual projects. This was especially true on the mainline HOV lanes. All classes of drivers on the controversial Alameda-580 project viewed the preferential lanes unfavorably; however, drivers who use Marin-101 and the San Berndadino Busway were generally more tolerant of HOV projects. Relatively few drivers on these two projects opposed the idea of more freeway lanes for carpools. Among the users of ramp bypass lanes, San Diego drivers viewed the idea of dedicated freeway lanes more favorably than did Los Angeles drivers. Some of the Los Angeles opposition seemed to reflect the much-publicized controversy that surrounded the ill-fated Santa Monica Freeway diamond lanes in 1976 (3).

Perceptions of Enforcement

One of the major differences among the projects themselves may be found in the perceived enforcement level reported by drivers. Drivers on mainline HOV lanes were much more aware of CHP enforcement activities than were drivers who use the survey ramps in Los Angeles and San Diego (see Figure 11). Only 14 percent of the mainline HOV-lane users said that they had never seen CHP enforcement of occupancy violations, but 38 percent of the San Diego ramp users and half of the Los Angeles ramp users responded that way. Although these differences in awareness certainly reflect the relative emphasis on enforcement on the different projects, they also provide insights into the impression made by different enforcement techniques. On the San Bernardino Busway, where violators are usually apprehended and ticketed in the buffer lane in full view of passing motorists, only 13 percent of all respondents said they had never seen the CHP ticketing violators. On Marin-101, however, where the CHP must escort violators to the side of the freeway before a ticket is issued, 26 percent of all respondents reported that they had never seen an occupancy citation issued. On one San Diego ramp that has a scanty refuge area that forces officers to pursue violators and issue tickets some distance from the ramp itself, 70 percent of all respondents reported they had never seen a citation issued for illegal use of the carpool lane. On a nearby ramp that has an ample refuge area where CHP officers could stand and wave over violators in full fiew of other drivers, the corresponding percentage was 25 percent.

Figure 11. Perceptions of enforcement levels.



Only about 10 percent of the drivers on all projects, except Alameda-580, thought that current enforcement levels were sufficient. On Alameda-580, however, 33 percent of the respondents thought that there was no need for the CHP to enforce more often.

Perceptions of Violations

The violation levels perceived by drivers also vary from project to project. When asked, "What percentage of the drivers in the bus-carpool lane would you estimate use the lane illegally?" drivers on mainline HOV lanes consistently overestimated the actual violation rates. Los Angeles drivers asked to estimate the relative number of bypass lane violators tended to underestimate, and San Diego drivers guessed that the lane violation rates on the I-15 and I-805 interchanges were higher than the actual rate computed from roadside observations. Driver estimates of violation rates cover a narrower range than do roadside observations, which indicates that drivers may tend to overestimate low violation rates and underestimate high rates.

Drivers on Alameda-580 were less concerned than other drivers about the presence of violators, which is presumably a reflection, again, of the adverse media publicity and public hostility directed toward the project. Of the Alameda-580 respondents, 43 percent thought that lane violations are no problem. Similar attitudes from drivers on other projects typically constituted only 15-20 percent of the responses received.

Attitudes Toward Ramp Metering

Overall, survey responses seem to indicate that ramp users have mixed feelings about the benefits of ramp metering. Although 70 percent of Los Angeles ramp users and 66 percent of San Diego ramp users agree that metering has improved freeway flow, only 14 percent of all Los Angeles respondents and 21 percent of their counterparts in San Diego thought that metering has shortened their overall trip time. Over half of all ramp users thought that ramp metering has no effect on their overall travel time and one-third of them believed that it has actually increased their travel time.

Perceived Time Savings

Drivers on both mainline HOV lanes and sample ramps that have bypass lanes were asked how much time they save by using the preferential carpool lanes. Tabulations of results show that drivers who respond to this question wildly overestimate the amount of time saved by using the carpool lanes (see Table 4). In each case, violators, carpoolers, and general drivers alike greatly overestimated the average time savings available to carpoolers.

One interpretation for the wide discrepancy between perceived time savings and actual time saved may be that differences tend to be amplified when one lane (i.e., the carpool lane) is moving while the other is not. In addition, the survey drivers may tend to cite the time savings available driving the worst freeway congestion (or longest meter delay) that they remember. This tendency to perceive greater time savings in the carpool lane, however, undoubtedly makes the carpool lanes appear more attractive to drivers than to statisticians and

Table 4. Driver estimates of HOV-lane time savings.

Lane	Time Savings (min)	
	Perceived	Measured
Ramp bypass		
National, LA-10	5.4	2.4
Woodman, LA-101	2.5	0.7
Vernon, LA-11	5.1	2.0
Olympic-Pico, LA-405	2.4	0.3
Colorado, LA-5	4.4	0.2
Orangethorpe, LA-91	3.1	0.4
Mainline HOV		
San Bernardino Busway	13.9	5-7
Alameda-580	6.9	<0.3
Marin-101	6.6	<0.3

indicates that there may be a psychological advantage in providing a carpool lane, even when the available time savings appear minimal. The illusion of greater time savings also helps to explain the relatively high violation rates observed on ramps in the face of negligible delays.

PRELIMINARY FINDINGS

Key findings with respect to violator behavior, enforcement effectiveness, and driver attitudes are summarized below.

Violator Behavior

On mainline HOV lanes that do not have barriers to separate the preferential lanes from the general flow of traffic, violations are heaviest at the fringes of the morning and evening operating hours.

Little correlation was found between violation rates on ramps and the time saved by bypassing the queue in the metered lane. Although violation rates increase slightly with the delay in the queue, and rose to an average of 19 percent for delays of 2 min, the violation rate recorded for delays under 20 s was a still-formidable 12 percent, and many violations were observed when there was no queue at all. Given the same total delay, drivers appear to be more willing to stay in a long queue that is moving relatively fast than in a short queue that is moving very slowly because of a long meter cycle time.

The number of drivers who fail to stop at the red signal light on a metered ramp is relatively low (less than 4 percent of all drivers on ramps without bypass lanes) and does not pose a major problem, particularly because such violations tend to occur when traffic volumes are low and ramp queues are short or nonexistent.

Enforcement Impacts

Even the lowest levels of special enforcement tested to date (one officer, 1 day/week, for 1 month) have had a significant impact in reducing violation rates on most HOV projects. Moreover, the residual effects of special enforcement actions have kept violation rates from returning to normal for at least 4-8 weeks after the actions have ceased.

Special enforcement appeared to be most effective on ramps where violation rates were previously high. On ramps where ramp violation rates were already low (i.e., under 4 percent), special enforcement seems to have less impact on reducing occupancy violations further, and violation rates returned to preenforcement conditions much faster. In the absence of enforcement, ramp violation rates can be expected to increase over time to the point at which meter effectiveness is minimized.

Driver Attitudes

Although the attitudinal differences that separate violators, carpoolers, and general drivers on a particular project are few and generally predictable, major differences separate the attitudes and perceptions of drivers on different HOV projects. Drivers are much more aware of in-place enforcement actions conducted in refuge areas near the HOV facility than of citations issued on freeway shoulders some distance from the facility.

More than two-thirds of the drivers on metered freeways feel that metering has improved freeway flow; however, less than 21 percent feel that it has shortened their individual trip times. Violators, carpoolers, and general drivers alike greatly overestimated the average time savings available to carpoolers from using HOV lanes, which indicates that there may be a psychological advantage in providing carpool lanes even when the available time savings appear minimal.

FUTURE DIRECTIONS

The findings of this paper must necessarily be regarded as preliminary, because data are still being assembled on citation rates and enforcement tactics, and a second wave of special enforcement activities has been scheduled on each sample TSM project. The impacts of these activities will be monitored to gain further insights into the relation between enforcement and violation rates. In addition, the effects of enforcement on freeway performance will be investigated, accident rates before and after the introduction of TSM projects will be analyzed, and the effects of increasing routine enforcement levels in the absence of special enforcement will be tested in two CHP command areas.

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