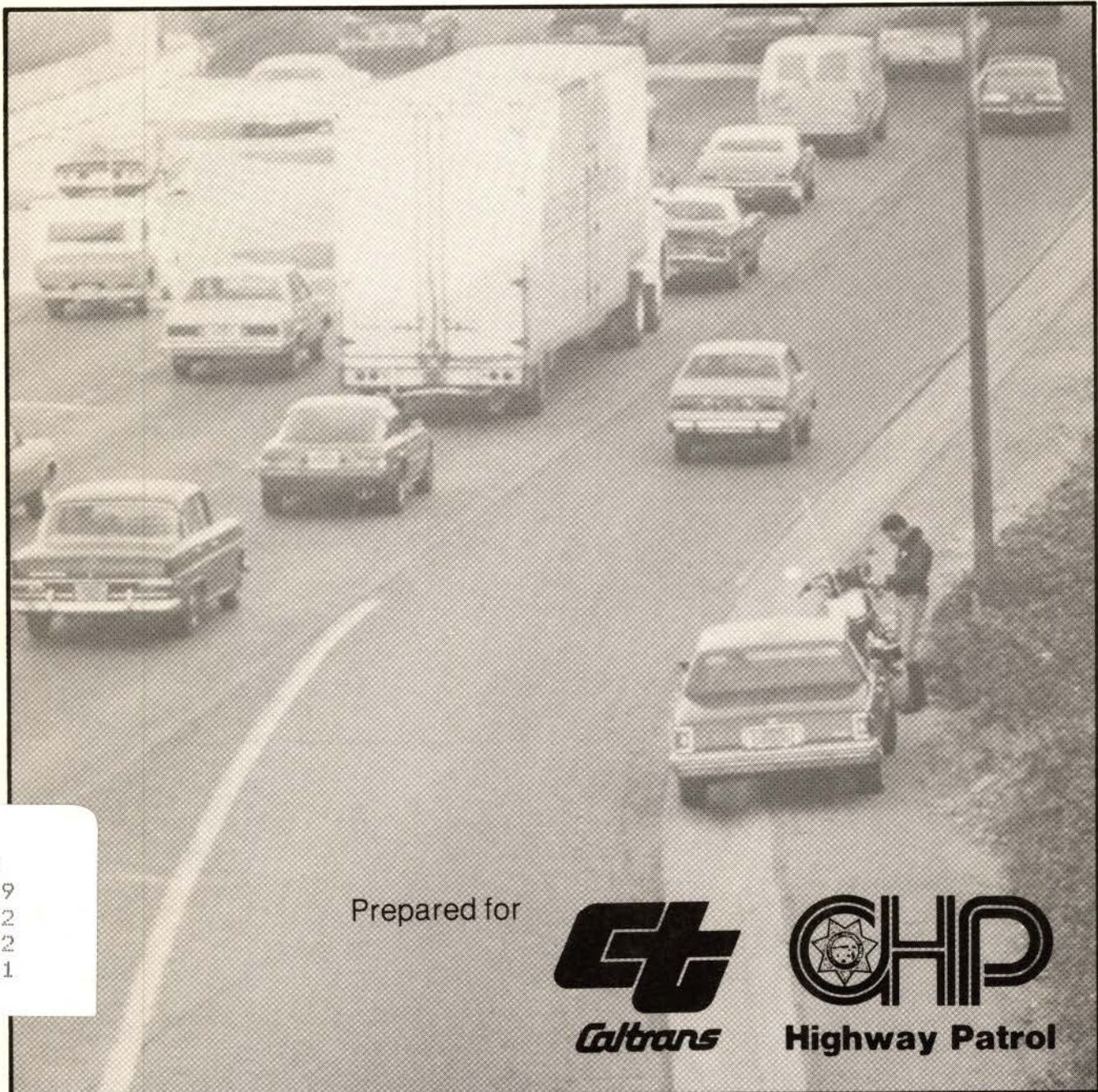




U.S. Department
of Transportation

October 1981

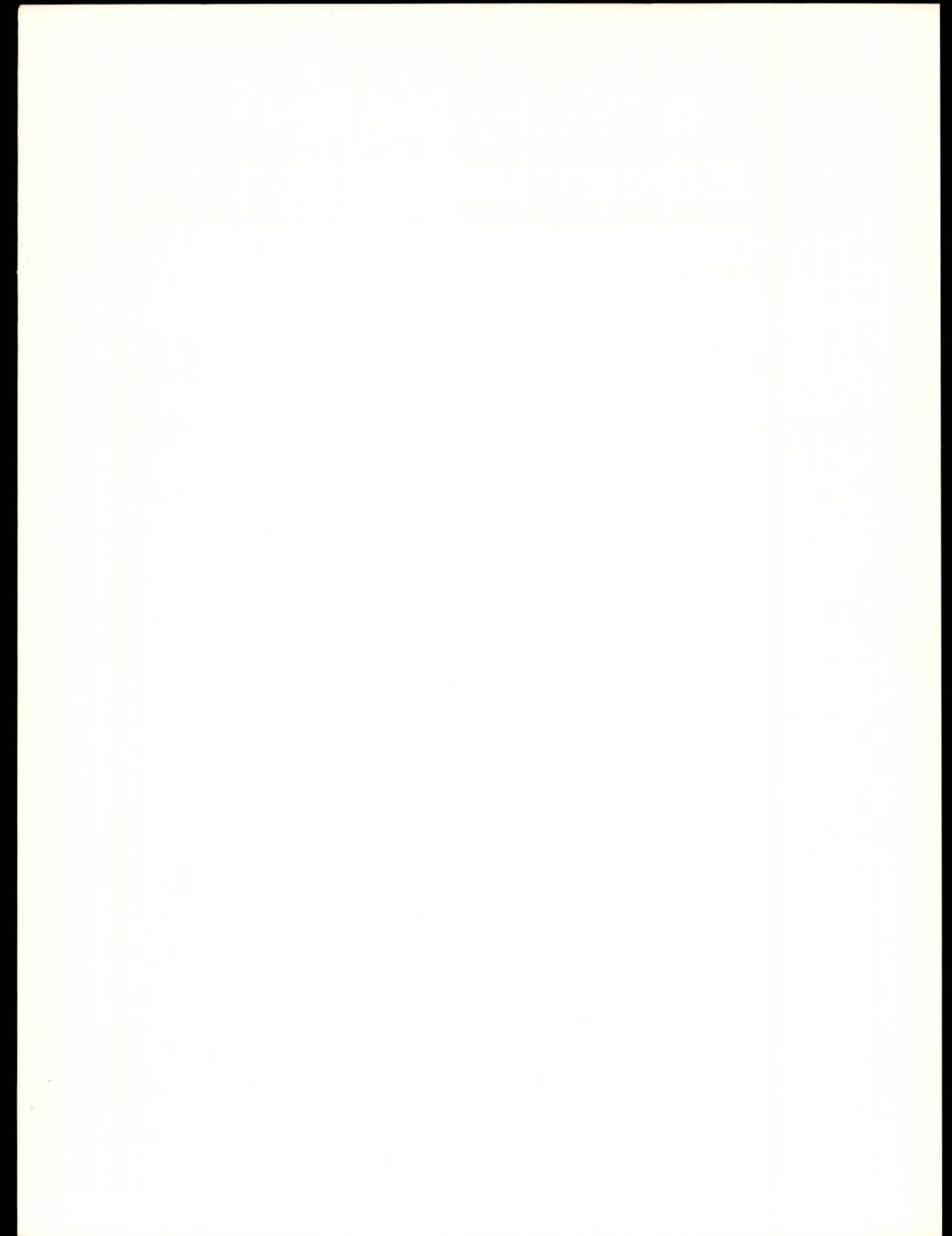
TSM Project Violation Rates: Executive Summary



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TSM PROJECT VIOLATION RATES

Executive Summary

*Prepared by Systan Inc. for
State of California Department of Transportation
and Department of the California Highway Patrol*



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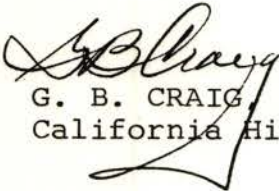
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FOREWORD

The fiscal constraints of the past decade and the accompanying pressure to exercise greater responsibility in the expenditure of public dollars have resulted in significant changes in our approach to solving transportation problems. Large capital outlays for new facilities are no longer commonplace. Instead, efforts are being made to maximize the use of existing facilities through a variety of transportation systems management (TSM) strategies. The success of these strategies is largely dependent upon public compliance with TSM regulations. Control of TSM violation rates, therefore, has become one of the many challenges confronting public agencies responsible for operating the transportation system. Unfortunately, very little information is available regarding TSM violation rates.



This publication is the final report on a two-year joint effort between the California Highway Patrol, the California Department of Transportation and Systan, Inc. The TSM Violation Rate Study was designed to quantify the effect of various enforcement, engineering and public education strategies on TSM violation rates. We feel the project has been very successful and should prove invaluable in the design and operation of TSM facilities nationwide.


G. B. CRAIG, Commissioner
California Highway Patrol



PREFACE AND ACKNOWLEDGMENTS

This is the final report on a twenty-month study designed to measure and evaluate the effect of different enforcement levels and strategies, engineering features, and public education programs on violation rates for various Transportation System Management (TSM) projects, particularly those involving preferential treatment for high-occupancy vehicles.

The report has been prepared in the Los Altos, California offices of SYSTAN, Inc. under Contract No. C-435-79/80 with the Department of the California Highway Patrol (CHP). The project was jointly sponsored by the California Department of Transportation (CALTRANS) with funding provided by the Office of Traffic Safety of the California Department of Transportation. Chief J.E. Smith, Commander of the Highway Patrol's Planning and Analysis Division, served as project director, and Captain Maury Hannigan of the Long-Range Planning Section of that Division was the CHP's project manager.

A steering committee comprised of representatives from the CHP, CALTRANS, the Office of Traffic Safety, and the public at large was responsible for overall project guidance and for approving the products of major project tasks. In addition to Chief Smith, other members of the steering committee were: Chief William Oliver of the CHP's Sacramento Office; Mr. David Roper of CALTRANS District 07; Mr. William Schaeffer of CALTRANS' Sacramento Office; Mr. Thornton Piersall of the League of California Cities; Mr. David Grayson of the Automobile Club of Southern California; and Mr. G. Van Oldenbeek of the Office of Traffic Safety.

SYSTAN's project manager and principal investigator was Dr. John W. Billheimer. Other SYSTAN staff members assigned to the study included: Ms. Juliet McNally, who was responsible for data coordination, survey analyses, and the accident investigation; Mr. Robert Trexler, who supervised statistical analyses and the investigation of mainline HOV lanes; Mr. Andrew Canfield, who supervised data processing activities; and Ms. GiGi Gillson and Ms. Leslie Pera, who organized and prepared the final report. Mr. Jesse Glazer of Crain and Associates assisted with the study of the San Bernardino Busway. Professor Adolf D. May, Mr. Walter Okitsu, and Mr. Tsutomu Imada of the University of California's Institute of Transportation Studies used their computer models of freeway operations to help provide insights into the impact of violations on traffic flow.

Liaison with CALTRANS and CHP field personnel throughout the state was accomplished through a coordinating committee chaired by Sgt. Tom Boswell of the CHP. Coordinating committee representatives in each major metropolitan area were:

<u>AREA</u>	<u>CHP Member</u>	<u>CALTRANS Member</u>
San Francisco	Sgt. Hal Koehncke	Mr. Len Newman
Los Angeles	Lt. William Russell	Mr. Gary Bork
San Diego	Lt. Lee Denno	Mr. Stuart Harvey

The study has profited greatly from the assistance of many other individuals within CALTRANS and the CHP. Robert Goodell and Arnold Mahelona of CALTRANS District 07 supervised the collection of operational data and provided a wealth of insights regarding TSM projects in and around Los Angeles. James McCrank of CALTRANS District 04 provided a similar service in San Francisco, as did Lawrence Wherry of CALTRANS District 11 in San Diego. Data and insights regarding the operation of the San Bernardino Busway were supplied by Hank Harada and Hank Brockmann of CALTRANS District 07. Sgt. Mike Maples of the CHP's Sacramento Headquarters oversaw the collection and coordination of enforcement records and acted as the project's liaison officer, while Officer John Novak helped to provide liaison with the Command Areas within the CHP's Southern Division. Other individuals contributing their time to the various project committees included Chief Harold Jones, Chief W. Haas, Chief Harry Adair, Captain Keith Newman, Lieutenant William Dwyer, and Lieutenant Steve Wilkins of the California Highway Patrol; Mr. James Borden and Mr. Richard Ginsberg of CALTRANS; and Mr. Arnie Trotter of the Office of Traffic Safety. Mr. John Keller of the CHP's Long Range Planning Section monitored the study design and offered many valuable suggestions throughout the investigation.

This Report has been printed in two Volumes:

Volume I contains the Executive Summary

Volume II contains the Technical Report

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EXECUTIVE SUMMARY INTRODUCTION

THE PROBLEM

In recent years, several different Transportation System Management (TSM) strategies have been introduced on California freeways. These strategies have included ramp metering, preferential freeway lanes for high-occupancy vehicles (HOVs), and bypass lanes for HOVs at metered ramps. A number of factors have arisen to frustrate efforts to enforce the traffic laws accompanying these strategies; these include personnel limitations, enforcement priorities, public hostility, confusion, and physical constraints imposed by the geometry and engineering features of specific projects. As a consequence, violation rates have increased on certain TSM projects, and are likely to continue to increase as more and more projects are introduced and enforcement manpower is stretched thinner and thinner.

OBJECTIVES

Adequate control of violation rates on preferential HOV facilities and other TSM projects requires an effective mixture of enforcement, engineering design changes, and public education. Although past operating experience with TSM strategies has given the California State Department of Transportation (CALTRANS) and the California Highway Patrol (CHP) a number of insights into the types of enforcement strategies, engineering changes, and education programs that might prove efficacious, 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 this study has been *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

The current study has covered nearly two years, with interim reports prepared after the sixth and twelfth months. This final report covers the full span of the project, including the implementation phase; pre- and post-enforcement surveys; four waves of special enforcement activities; investigations of special design features, safety aspects, and the costs and benefits of TSM project enforcement; and the development of a recommended program of future enforcement for California HOV lanes.

Projects Evaluated

Mainline HOV Lanes. In the case of mainline HOV lanes, the different engineering options evaluated were limited to the major projects currently in place on California free-ways. These projects are summarized below.

Type of HOV Lane Separation	Baseline Lane Violation Rate	Refuge Area	Engineering-Related Enforcement Problems
Non-Separated: Marin 101	21.5%	Minimal	Narrow lanes and minimal median make it desirable to escort violators across heavy traffic to shoulder.
Buffer-Lane: Alameda I-580	30.5%	Median Lane	Median occasionally used for enforcement. Majority of violators are escorted to right shoulder or apprehended after leaving lane.
San Bernardino Busway (East End)	8.8%	Buffer Strip	Buffer strip is used as a refuge area for enforcement, or violator is escorted to far right shoulder.
Physical Barrier: San Bernardino Busway (West End)	3-4%	Bus Stations, Widened Refuge Areas	Violators are stopped at bus stations, or pulled over in marked refuge areas.

Ramp Bypass Lanes. In the case of ramp bypass lanes, the full spectrum of lane designs represented on California freeway ramps was tested to determine the impact of design characteristics on enforcement and violations. Existing bypass lanes were classified in groups according to a number of important geometric features, design choices, and performance characteristics, including the availability of a refuge area, the visibility of the enforcing officer, and the current violation rate. Over one-third of the more than 130 ramp bypass lanes operating in Los Angeles at the start of the study were analyzed in detail, along with all bypass lanes in San Diego and the San Francisco Bay Area. In addition to the variety of characteristics available for analysis on existing ramps, certain innovative engineering options were tested during the study. These included:

- Metered HOV bypass lanes;
- Special signing and striping; and
- Separated HOV bypass lanes.

Other Projects. A small sampling of metered ramps without bypass lanes was also investigated, along with the preferential lanes at the toll plaza of the San Francisco/Oakland Bay Bridge.

Enforcement Options

Different levels and combinations of routine and special enforcement were tested to ascertain their effectiveness in controlling violations both on newly opened projects and on those that had been operating for some time. CHP officers were assigned, singly or in teams, to particular bypass lanes and other HOV projects for a specified number of days over periods of one, four, or twelve weeks. Typically, special enforcement assignments covered the entire peak commuting period for one, two, or four days per week. Particular attention was paid to the behavior of motorists after special enforcement activities ceased. In addition, an enhanced version of routine enforcement was studied in which every beat officer on duty during the morning and evening peaks was instructed to spend ten minutes per day on ramp enforcement.


Education Options and Public Attitudes

Motorists violating TSM project restrictions affect and are affected by the climate of public opinion surrounding the projects. Violators and non-violators alike were surveyed early and late in the evaluation to document prevalent statewide attitudes and measure perceptions of routine and special enforcement. Media coverage was monitored throughout the evaluation, and the impact of a TV campaign on bypass lane violations was analyzed in the San Diego area.

Data Collection Patterns

A typical pattern of field observations for a specific HOV project is shown below.

TYPICAL PATTERN OF FIELD OBSERVATIONS

	(BEFORE) MONTHS 1-3	MONTH 4	MONTH 5	MONTH 6	...	
ROADSIDE OBSERVATIONS	✓✓✓*	✓	✓✓✓	✓	✓✓*	...
ENFORCEMENT	ROUTINE	SPECIAL 	ROUTINE	ROUTINE	...	

*AS NEEDED

The pattern called for two or three days' observation of violation rates prior to the introduction of special enforcement activities, followed by as many as five observations during the two months following these activities. Four waves of special enforcement were scheduled on ramp bypass lanes, and at least two separate waves were tested on each mainline HOV lane. Throughout the evaluation, special enforcement activities were scheduled sequentially, so that the results of on-going analysis and the observations of enforcement personnel could be used to direct subsequent testing.

HISTORICAL ENFORCEMENT LEVELS AND VIOLATION RATES

As a first step in accomplishing the study objectives, existing California TSM projects were surveyed, future plans for such projects were documented, and current statistics were assembled describing violation rates, enforcement levels, and operating performance on current and past TSM projects in California. Exhibit S.1 summarizes these statistics for the Spring of 1980, prior to the introduction of any special enforcement programs.

Mainline HOV Lanes

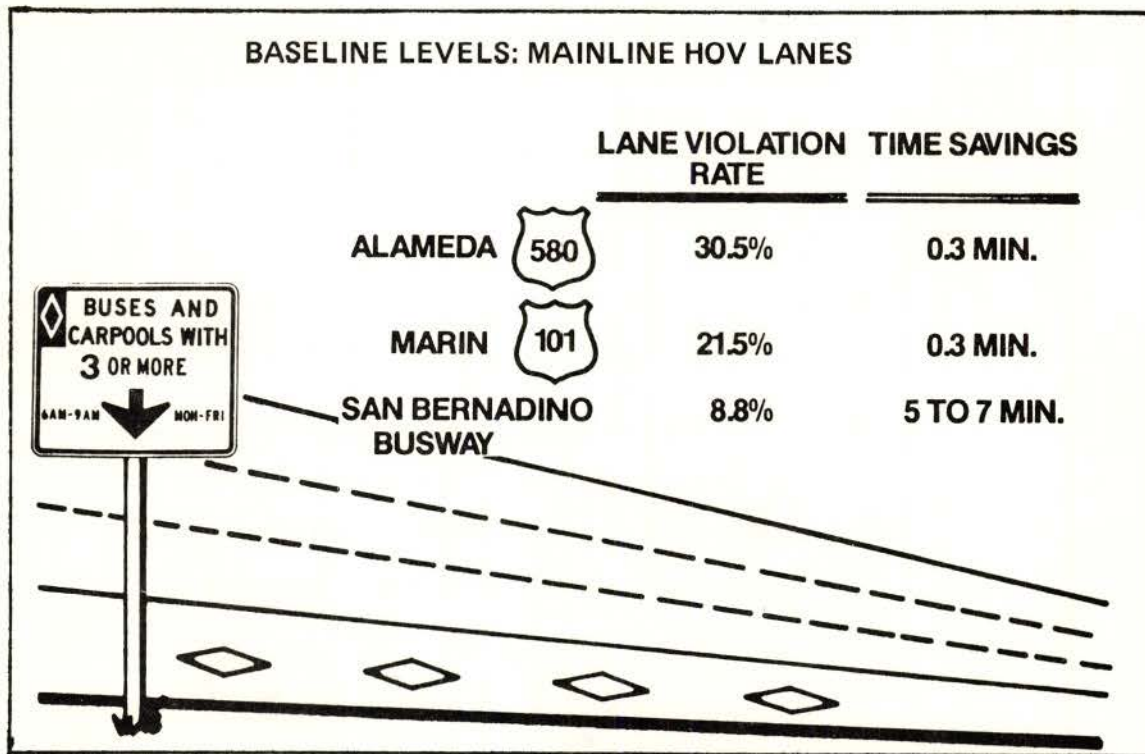


Exhibit S.1
TSM PROJECT VIOLATION RATES
and
ROUTINE (HISTORICAL) ENFORCEMENT LEVELS
 (Base Period Data – Spring, 1980)

PROJECT	VIOLATION DATA		ENFORCEMENT DATA		OPERATING DATA
	Lane Violation Rate	Ramp or FWY Violation Rate	Past Citation Rates	Apprehension Rate	Average HOV Time Savings (Mins During Peak Hour)
MAINLINE HOV LANES					
Non-Separated Lanes:					
Marin 101	21.5%		11.6/day	2.6%	Negligible (average under 20 seconds)
Santa Monica*	15.1%	1.0%	55/day		5-6
Separated Lanes:					
Alameda I-580	30.5%		2.5/day	0.8%	Negligible (average under 20 seconds)
San Bernardino	8.8%		10.8/day	3.3%	5-7
METERED RAMPS					
Without Bypass Lanes:	3.8%**	3.8%**	N/A	N/A	N/A
With Bypass Lanes:					
Los Angeles	37.7%	12.8%	.27/ramp/day	0.18%	1.3
San Diego	19.5%	3.0%	.07/ramp/day	0.24%	0.4
EXCLUSIVE HOV BRIDGE LANE					
S.F.-Oakland Bay Bridge	5.4%	0.7%	2.4/day	1.1%	4-5

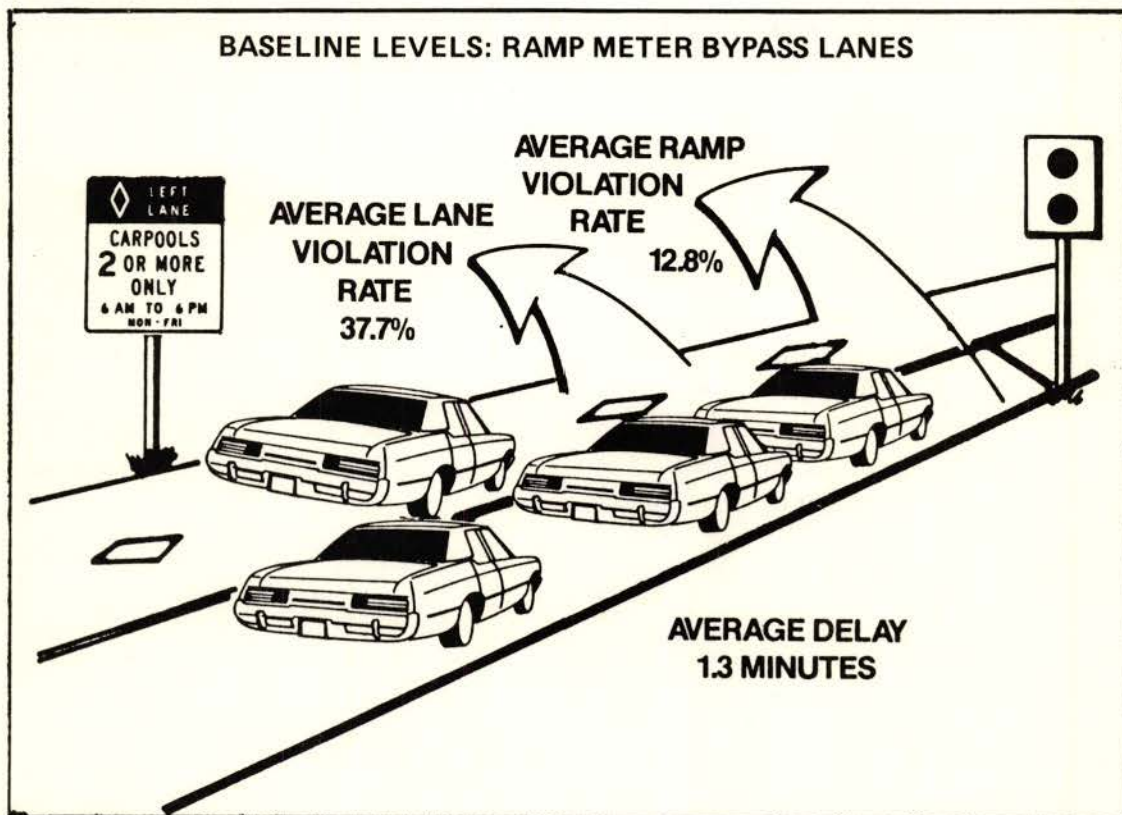
*Project Discontinued

**Meter Violation Rate

Enforcement Levels. Past citation rates on mainline HOV lanes ranged from a low of four tickets per weekday on Alameda 580 to 14 tickets per weekday on the San Bernardino Busway. On Alameda 580, the CHP has historically relied on routine enforcement to control violation rates, while motorcycle officers have been assigned to special enforcement duties during the evening peak on Marin 101. On the San Bernardino Busway, a combination of routine and special enforcement has been used, with special enforcement units assigned intermittently to lane enforcement.

Violation Rates. The percentage of vehicles using California mainline HOV lanes illegally during the spring of 1980 ranged from 8.8% on the San Bernardino Busway to 30.5% 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% of all vehicles in the lane during the morning peak and 10.5% of all vehicles in the afternoon. These violation rates were lower still (estimated at 3% to 4%) on the portion of the Busway where a physical barrier makes lane-switching impossible. While violation rates on the San Bernardino Busway and Alameda 580 had not increased appreciably over prior measurements, the 21.5% violation rates recorded on Marin 101 represented an increase over the violation rates of 5% to 15% reported roughly one year earlier.

Ramp Meter Bypass Lanes



Enforcement Levels. In the past, the CHP has applied a policy of relatively low-priority, routine enforcement to bypass lanes, using available personnel to enforce the lane restrictions in addition to regular patrol duties. As the number of bypass lanes in Los Angeles approaches 150, 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 over one per week at the start of this study.

Violation Rates. Under this enforcement policy, violations increased annually on most ramp meter bypass lanes in the Los Angeles area, and bypass lanes that had been operational for several years had significantly higher ramp violation rates than newly-opened lanes.

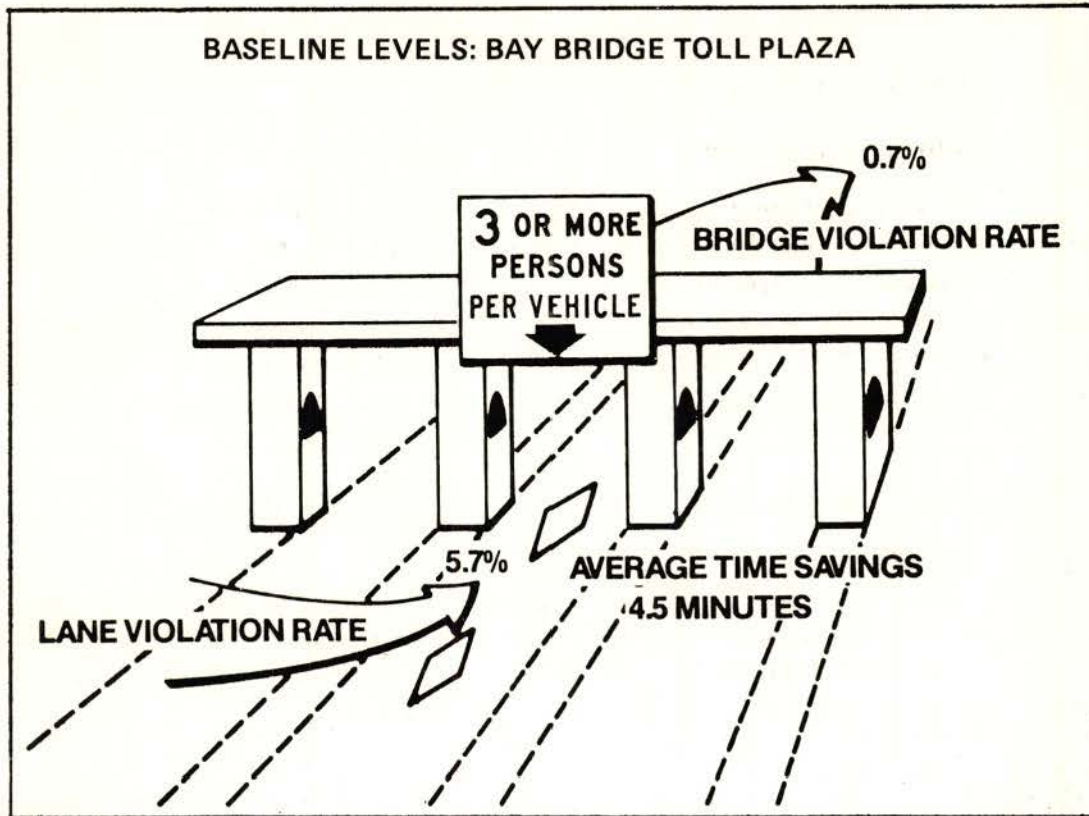
Prior to the start of this study the average lane violation rate for a sampling of 39 metered ramps with HOV bypass lanes in the Los Angeles area was 37.7%, appreciably higher than the comparable violation rate on any mainline HOV project in California. This corresponded to an average ramp violation rate of 12.8%. In Los Angeles, the relative number of vehicles using bypass lanes illegally ranged from 13.4% on one heavily-enforced ramp (Colorado Boulevard on LA5) to over two-thirds of all vehicles in the bypass lane on the Western Avenue ramp to the westbound Santa Monica freeway.

HOV lane violation rates were found to be considerably lower (averaging 19.5% on a sampling of seven HOV bypass lanes — a 3.0% ramp violation rate) in San Diego, where the peak traffic periods are shorter, meters are traffic-responsive, and the HOV lanes themselves are meter-controlled.

Ramp Meter Violations

The number of drivers ignoring 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 non-existent. 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 1% of all vehicles on the ramp), as the bypass lane itself provides a convenient pathway to those potential violators who might otherwise simply run the red light.

Bridge Toll Plaza



Two lanes of the 17 westbound lanes approaching the toll plaza of the San Francisco/Oakland Bay Bridge have been reserved for the exclusive use of carpools with three or more occupants, while a third lane is reserved for buses. These lanes provide free passage through the toll booth, and preferential treatment at the meters controlling access to the bridge itself, thereby saving carpools and buses from 4 to 5 minutes in their morning commute, as well as the 75-cents bridge toll.

Although these savings are consistently higher than those available to drivers on most other HOV projects in California, the 5.4% lane violation rate on the Bay Bridge was the lowest baseline level recorded on any HOV project, representing less than 1% of all vehicles using the toll plaza. The CHP regularly deploys five or six officers on the Bay Bridge during the peak morning commute hours, and in the past, special enforcement teams of three to four additional officers have been assigned to bridge enforcement duty on an irregular basis to keep violation rates from rising.

ENFORCEMENT IMPACTS

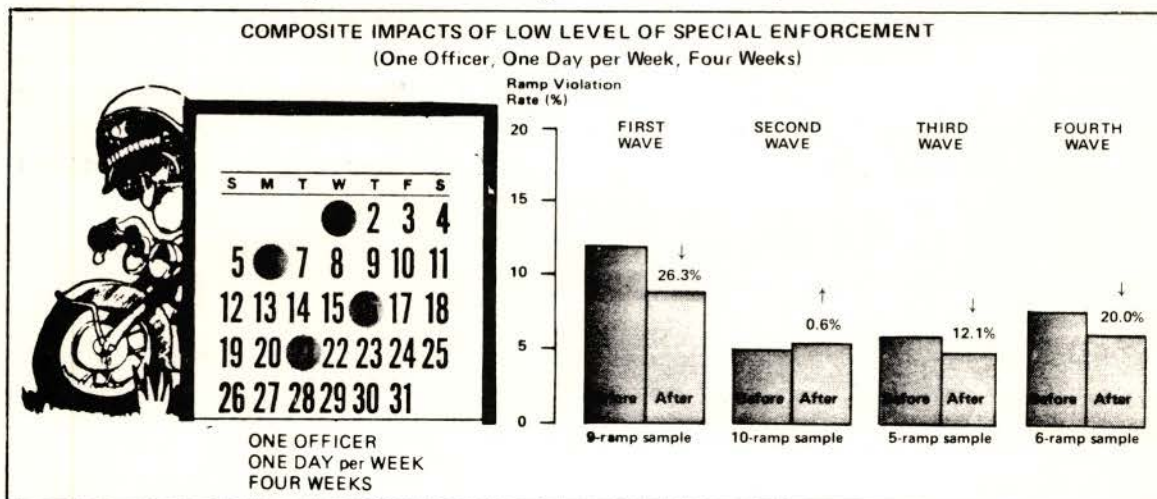
RAMP METER BYPASS LANES

Special Enforcement Activities

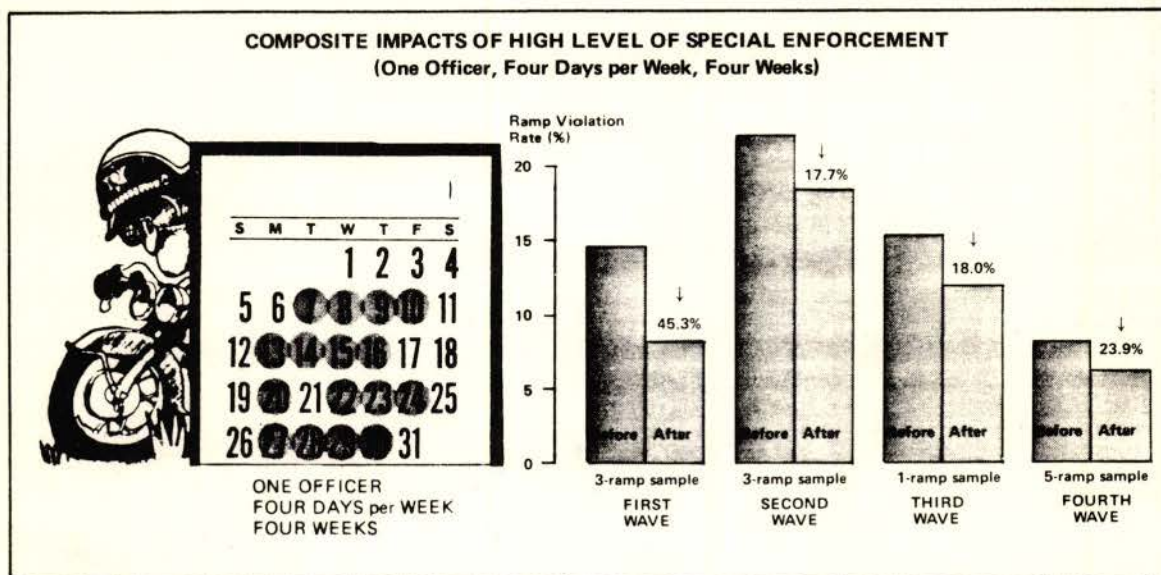
Four waves of special ramp enforcement activities were scheduled in Los Angeles, San Diego, and San Jose between June 1980 and August 1981. During each enforcement wave, officers were assigned to particular ramps for a specified number of days each week for periods of one week, four weeks, or twelve weeks. These special assignments were applied randomly and interspersed with periods of routine enforcement lasting at least nine weeks. The composite results of each wave of enforcement are summarized below:

COMPOSITE IMPACTS OF SUCCESSIVE SPECIAL ENFORCEMENT WAVES (Ramp Violation Rates)				
TIME PERIOD	First Wave June-Sept 1980 (37 ramps)	Second Wave Sept-Dec 1980 (27 ramps)	Third Wave Jan-April 1981 (34 ramps)	Fourth Wave May-Aug 1981 (32 ramps)
Before Enforcement	11.8%	8.9%	8.7%	8.6%
During Enforcement	7.6%	7.8%	7.1%	6.7%
After Enforcement	7.9%	7.9%	7.4%	7.2%
% Change	-32.7%	-12.2%	-14.3%	-16.9%

The first wave of enforcement was easily the most effective in reducing violation rates. During the first wave, special enforcement activities proved successful in reducing occupancy violations on almost every ramp where they were tried. Even the lowest levels of special enforcement (one officer, one day per week, for four weeks) had a significant, measurable impact in lowering violation rates (see below). Moreover, violation rates tended to remain low for as long as four to eight weeks following the cessation of special enforcement activities.



Although the relative effectiveness and residual impact of special enforcement diminished somewhat following the first wave, heavier enforcement levels (enforcement two or more times a week) still caused violation rates to decline (see below), and the lower enforcement levels (enforcement once a week or less) generally managed at least to keep rates from rising and maintain earlier reductions.



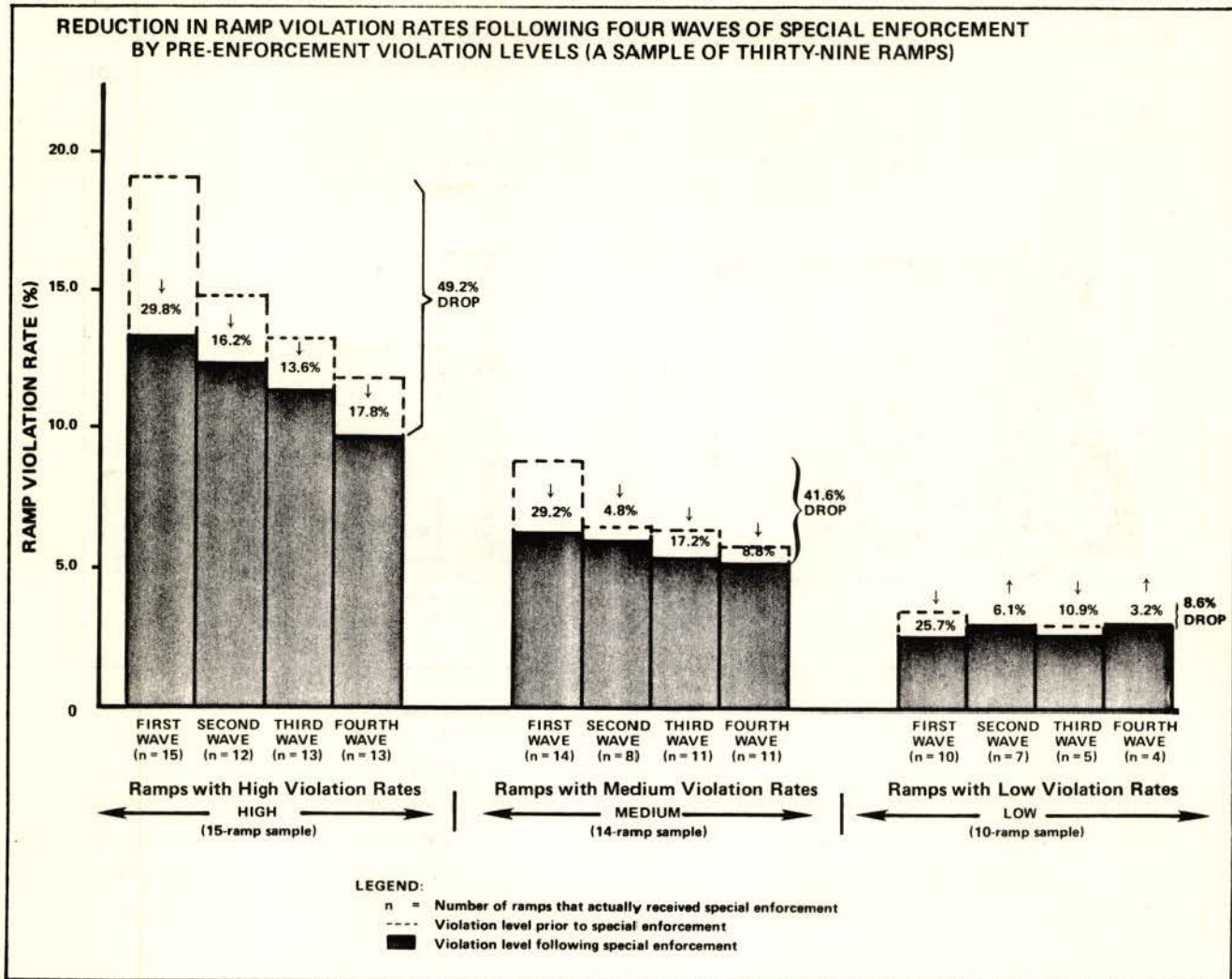
At the close of the fourth wave, violation rates on the ramps subjected to special enforcement stood at 6.5%, a 45.4% reduction below the 11.9% rate characterizing those ramps at the start of the study. In all, close to 10,000 citations were issued during special ramp enforcement efforts, and the number of violations on the average ramp dropped by 72 violations per day. The median span of time before violation rates approached pre-enforcement levels was two weeks following the later waves of enforcement, as compared with eight weeks following the first wave.

Special Enforcement Tactics

The most popular and effective tactic for enforcing ramp bypass lanes required that officers park their vehicles beyond the meter, and assume a stationary position to wave violators over to a safe refuge area where a citation could be issued. Officers who were able to stand out of the view of potential violators issued more citations per day than officers who assumed more visible positions. Some officers appreciated the extra margin of safety afforded by in-view enforcement, however, and these officers tended to be no less effective in reducing violations. Violations were somewhat slower in returning to pre-enforcement levels when enforced from less visible positions.

Enforcement tactics involving vehicle pursuit were much less efficient than stationary enforcement in generating citations, reducing violations, and providing a cautionary example to other ramp users.

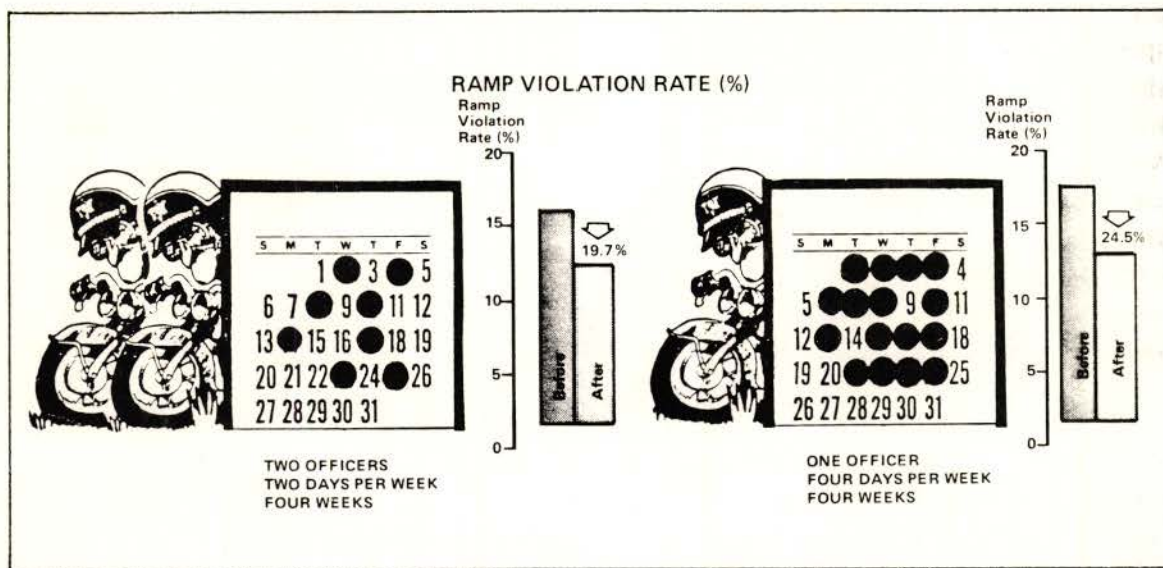
Special Enforcement Impacts



Effect of Violation Levels. Special enforcement was most effective on ramps where violation rates were medium or high to begin with. On ramps where violation rates were already low (i.e., under 6.5%), special enforcement had less impact in reducing occupancy violations further, and violation rates returned to pre-enforcement conditions much faster. This suggests that there is a practical limit on the reductions that can be brought about by enforcement, and consequently that special enforcement efforts should not be expended in an attempt to make tolerably low violation rates lower still.

The need to relate enforcement levels to existing violation rates underscores the need for close, continuing cooperation between the enforcement agency and the agency responsible for maintaining, operating, and monitoring ramp meter bypass lanes.

Duration of Special Assignments. Twelve-week periods of enforcement were not found to be significantly more effective than four-week periods either in reducing violations further or in generating longer residual impacts. The diminished effectiveness of longer periods of enforcement, coupled with the lessened impact of later waves of special enforcement and the difficulty of driving ramp violation rates below 4 or 5%, suggests that enforcement impacts are subject to a law of diminishing returns.

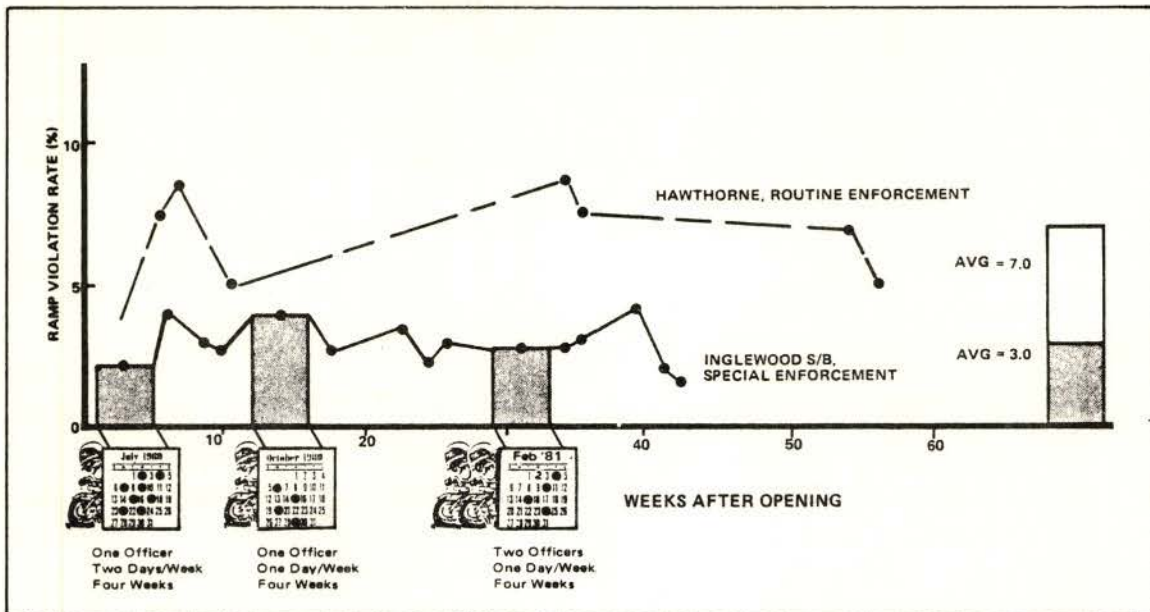


Number of Officers. Assigning two officers to a single ramp was almost – but not quite – as effective as assigning a single officer for twice as many days. On some heavily violated ramps, the officers themselves preferred working in pairs so that fewer violators went unticketed and help was close at hand in the event that apprehended drivers became unruly while waiting to be ticketed.

Bail Schedules. Bail schedules for HOV lane occupancy violations vary from \$21.00 to \$52.00 in the CHP's Southern and Golden Gate Divisions, and are set at a low of \$13.50 per offense in the San Diego area. There was little evidence that higher fines led to significantly lower violation rates, but a fine of \$13.50 does not begin to cover the publicly borne costs of apprehending violators and processing citations.

Impacts on Traffic Flow. As special enforcement encouraged more single-occupant autos to join the metered queue rather than use the HOV lanes illegally, queue lengths grew, and the average delay encountered by drivers entering Los Angeles freeways rose from 45 seconds to 54 seconds. In addition, special ramp enforcement actions were found to reduce speeds on adjacent freeways by between 20% and 30% in the vicinity of the ticketing activity.

Start-Up Strategies



Start-up enforcement strategies were tested by selecting matched pairs of newly-opened ramp bypass lanes similar in geometric configuration and enforcement visibility, and initiating special enforcement activities on one ramp of each pair, while restricting the other ramp to low-priority routine enforcement. Special enforcement activities lasted for four weeks and were repeated quarterly on certain ramps. After one year of ramp operation, ramps receiving special enforcement during the opening weeks had significantly lower violation rates than their opposite numbers. The composite ramp violation rate on ramps receiving special enforcement was 7.3%, as compared with a rate of 14.0% on control ramps exposed only to routine enforcement.

Special enforcement activities should be initiated immediately after a ramp is opened and be continued for at least two days a week during the first month of operations. If an initial grace period is desired, it should last no more than a week and should generally not be publicly announced. Officer presence should be maintained throughout that week to issue warnings, answer questions, and instill a degree of respect for the HOV restrictions.

Routine Enforcement

In the absence of special enforcement, routine enforcement proved to be an ineffective means of controlling ramp violation rates. Under a policy of routine enforcement, ramp violation rates in Los Angeles had risen steadily prior to the start of this study. Attempts to increase routine enforcement levels by requiring officers to spend ten minutes of each day on ramp enforcement also proved ineffective. Such efforts produced a low level of citations, were difficult to direct and control, were unpopular with some officers, and tended to encourage one-shot enforcement tactics involving pursuit rather than a sustained effort from a stationary position.

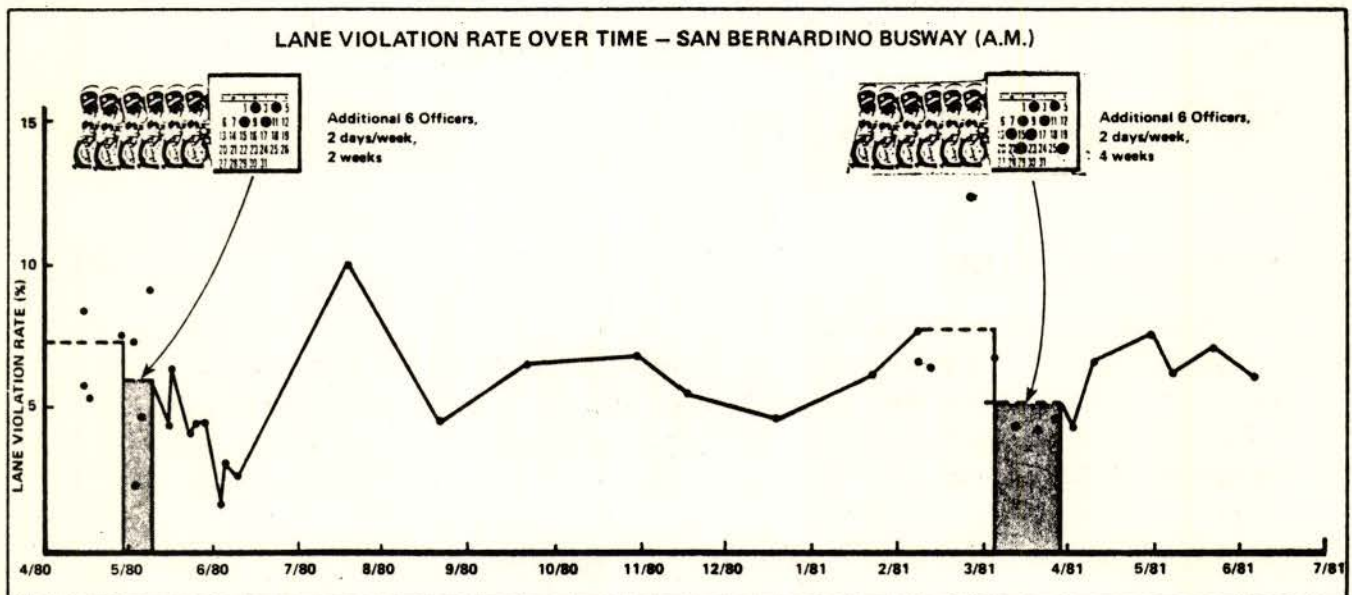
Routine ramp enforcement can be effective if applied in conjunction with special enforcement in a selective enforcement program. Violation rates rose relatively slowly during the periods of routine enforcement separating special enforcement sessions on sample ramps. As drivers became aware of special enforcement activities on sample ramps, moreover, violation rates dropped on other routinely enforced ramps. On six Los Angeles ramps subjected only to routine enforcement, violation rates dropped 20% between the first and fourth waves of special enforcement.

MAINLINE HOV LANES

Special Enforcement Activities

Two waves of special enforcement activities were scheduled on each mainline HOV lane in California between May 1980 and June 1981. During the first wave from two to four additional officers were assigned to each project for a two-week period in May 1980. During the second wave, a similar number of officers were assigned to enforce throughout either the morning or evening commute hours (but not both) for a period of four weeks. The first wave of special enforcement reduced violation rates significantly on all three projects. Violation rates on both Alameda 580 and the San Bernardino Busway remained lower than pre-enforcement levels for at least eight weeks, when the summer vacation period began. Marin 101 experienced large reductions during both the morning and evening peaks, even though special enforcement activities were only scheduled during the evening commute hours. The percent reduction, however, was smaller in the morning, and conditions returned to normal faster.

SPECIAL MAINLINE ENFORCEMENT SAMPLE RESULTS



On both Alameda 580 and the San Bernardino Busway, the second enforcement wave reduced violation rates during both commuting periods, even though special enforcement was limited to the evening peak in Alameda County and the morning peak on the San Bernardino Busway. Violations returned to pre-enforcement levels within two to six weeks after special enforcement ceased. For the morning peak in Alameda County and the evening peak on the Busway, however, these violation levels were significantly lower than those measured a year earlier at the start of the study. In Marin County, violation rates fluctuated wildly after the second enforcement wave, and reached levels considerably higher than those measured prior to enforcement. During the morning peak period, which had received only relatively low levels of routine enforcement throughout the study, violation rates on Marin 101 had doubled by the close of the study. There was no significant increase during the evening peak, which received higher levels of routine enforcement than any other TSM project.

The results of the study suggest that a program of selective enforcement, with a month of special enforcement undertaken at relatively infrequent intervals, is capable of controlling violation rates on mainline HOV lanes, so long as routine enforcement is not neglected during the intervening periods. Routine enforcement levels averaged two citations per peak period on Alameda 580, four per period on the San Bernardino Busway, and nearly eleven per period during the evening peak on Marin 101. It is cost-effective to concentrate special enforcement during any month in a single peak period, so long as neither peak is neglected in the long run. Enforcement should be concentrated most often in that direction which least interferes with traffic flow.

Impact of Enforcement on Traffic Flow

When mainline lanes are congested, special enforcement activities can cause further traffic disruption as gawkers slow to observe ticketing activities. To minimize the effect of these activities on mainline flow, special enforcement officers should avoid bunching together, limiting stacking so that no more than one car is waiting to be ticketed at any time (in addition to the vehicle being cited), release cited motorists into the busway rather than into the mainline lanes, and avoid pursuing violators across several lanes of traffic.

SPECIAL BRIDGE LANES

Most of the comments regarding the enforcement of ramp meter bypass lanes apply equally well to the enforcement of special toll plaza lanes. On the San Francisco/Oakland Bay Bridge, the practice of waving violators over into a coned-off refuge area proved more effective both in producing citations and in lowering violation rates than the practice of using motorcycles to pursue violators.

DESIGN IMPLICATIONS

Several aspects of HOV project design have a critical bearing on enforcement and violation rates. Foremost among these are the need for collaboration between design and enforcement agencies early in the planning process, and the requirement for adequate refuge areas to support field enforcement activities. Early collaboration between design and enforcement agencies will:

- open a channel of communication and promote cooperative relationships;
- insure that enforcement costs will be reflected in budget projections and alternatives analyses;
- incorporate enforcement requirements in project design; and
- provide advance warning so that field officers can be alerted to special enforcement requirements.

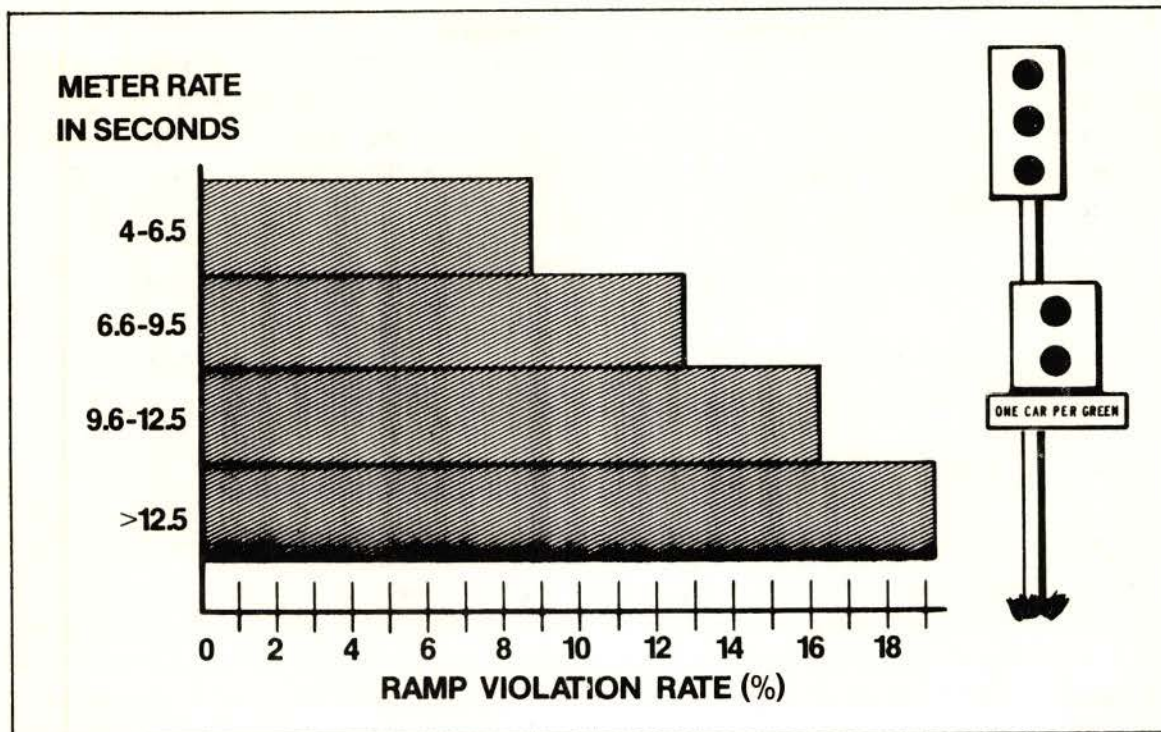
Adequate refuge areas for apprehending and ticketing violators are essential for the safe and efficient enforcement of ramp meter bypass lanes, mainline HOV lanes, and exclusive lanes at toll plazas.

RAMP METER BYPASS LANES

Impact of Design on Violations

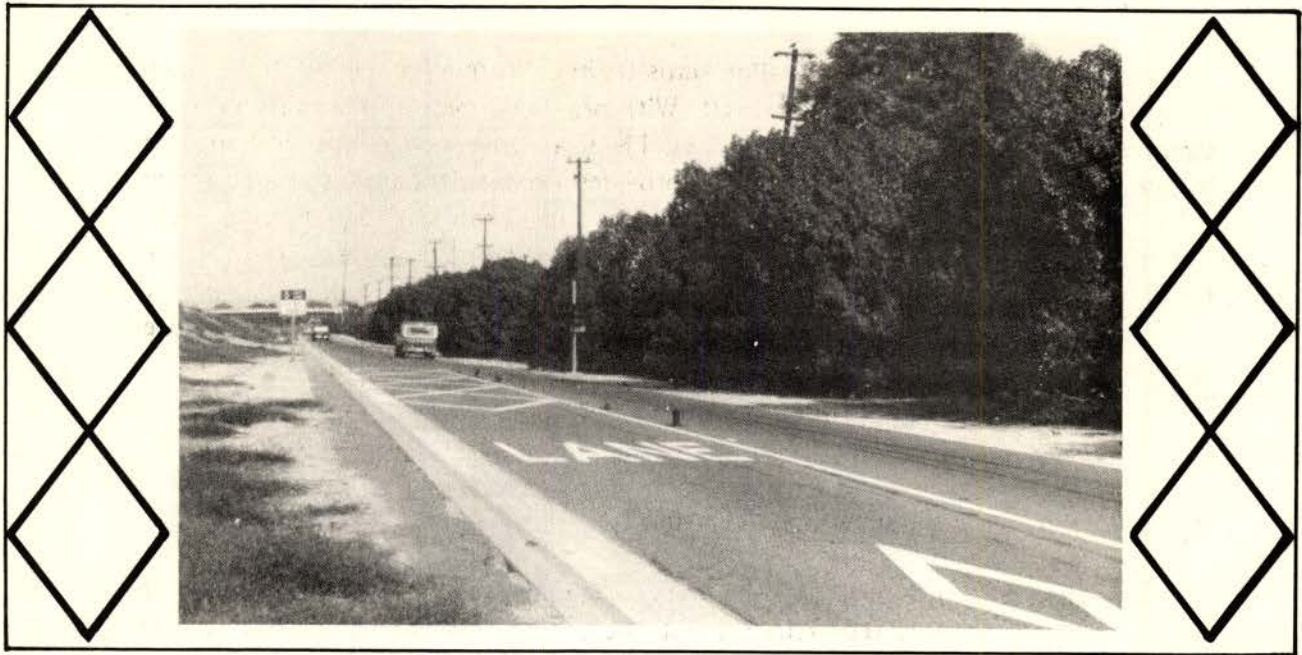
Delay. Driver delays on metered ramps are a function of both queue lengths and the designed metering rate. Little correlation was found between the duration of these delays and ramp violation rates. Although violation rates under conditions of routine enforcement increased slightly with the delay in the queue, rising to an average of 19% for delays of two minutes, the violation rate recorded for delays under 20 seconds was a still-formidable 12%. Drivers tended to overestimate the time to be saved by using the ramp bypass lanes, so that even the shortest delays were accompanied by significant violation rates. Short delays were not uncommon on Los Angeles and San Diego ramps, as the majority of the data points recorded by roadside observers reported delays of under 20 seconds.

IMPACT OF METER RATE ON RAMP VIOLATIONS



Metering Rate. Although violation rates varied widely and unpredictably with ramp conditions, there was some evidence to suggest that driver's perceptions of delay stemmed not so much from the queue length as from the metering rate. Given the same delay, drivers appeared to be more willing to stay in a long queue which was moving relatively fast than in a short queue which was moving very slowly because of a long red phase in the meter cycle.

Visibility. Geometric configurations which hid patrol officers from the view of potential violators contributed surprisingly little to the effectiveness of enforcement activities. Special enforcement actions taken from non-visible positions had slightly longer residual impacts than enforcement actions taken in full view of motorists entering the ramp. From the standpoint of reduced violation rates, however, the differences between the results of visible and non-visible ramp enforcement actions were neither striking nor statistically significant. Visible enforcement proved to be nearly as effective as non-visible enforcement, and many officers felt that added visibility increased the safety margin associated with roadside enforcement.



Special Striping. Sample ramps with bold stripes painted to form a continuous diamond pattern (see above) had significantly lower violation rates than ramps with conventional striping during the first six months of bypass lane operation. As time went on, however, the deterrent effect of special striping apparently diminished, and after nearly two years of operation, comparison tests showed no significant difference between violation rates on routinely enforced ramps with and without special striping. The first wave of special enforcement caused violation rates to drop appreciably on ramps with and without special striping, and the presence or absence of special striping apparently had little impact on violation rates during and after special enforcement activities.

Use of Delineators. Candlestick delineators separating the HOV lane and general traffic lane had no measurable effect on violations, and the short life span of the delineators made their use expensive as well as ineffective.

Trapping Ramps. Certain ramp designs have the potential for trapping law-abiding drivers against their will in reserved lanes, particularly when left-turns are permitted from a surface street onto a ramp which reserves its left-hand lane for buses and carpools. Violation rates are almost universally higher on these ramps when the right hand lane overflows onto the surface street, so that left-turning vehicles are trapped in the carpool lane. Such "trapping" designs pose special problems for both drivers and enforcing officers and should be avoided if at all possible. Problems are minimized on such ramps, and violation levels respond to enforcement efforts, when overflows are infrequent *and* relatively few autos make the turning movement which springs the trap. When most of the vehicles entering a ramp make the turning movement that can potentially leave them trapped in the carpool lane, however, violation rates are not likely to respond to enforcement. In such cases, carpool restrictions should be avoided and all lanes should be opened to general traffic.

Metering the HOV Lane. Violation statistics in California provide no strong support for or against metering the HOV lane itself. With pre-timed meters, more drivers run the red signal when both lanes are metered (3% vs. 1% of all drivers on ramps with an unmetered bypass lane) since the HOV lane no longer provides a convenient avenue around the metered signal. Meter violations are not noticeably higher when both lanes are metered with traffic responsive meters because the meters tend to be inoperative during slack periods when meter violations would be highest. Enforcement actions are somewhat simpler and safer when both lanes are metered, since occupancy violators are generally traveling slower after stopping to observe the red signal.

Impact of Violations on Freeway Performance

Less than twenty percent of the drivers using ramp bypass lanes illegally do so through maneuvering which could represent a direct safety hazard to other drivers. By using bypass lanes illegally, however, all violators represent an indirect threat to the long-term time savings, accident relief, and other benefits obtainable through metered ramp control. A sensitivity analysis undertaken on a model of a single roadway, the Santa Monica Freeway, suggested that violations are likely to have a disproportionate impact on these benefits.

The relationship of ramp violations to freeway flow is heavily dependent on the characteristics of the individual roadway, the number of ramps provided with bypass lanes, and the metering strategy selected. In most cases, however, the following general design procedures should limit the adverse impacts of ramp violations on freeway flow:

- Designers should treat the possibility of violations explicitly and assume a violation rate of 5% will exist on all ramps provided with HOV bypass lanes. Metering rates should be set to accommodate this level of violations.
- Sensitivity analyses should be undertaken to identify those critical ramps (generally those ramps just upstream from bottlenecks) on which violations are likely to have the most negative impact on freeway flow. On these ramps, designers should either provide no HOV bypass lanes or build a larger safety factor than the 5% level suggested above into the metering rate to offset the adverse impacts of violations.

MAINLINE HOV LANES

Hours of Operation

On Marin 101, violations tend to cluster on the fringes of the morning and evening operating hours, with a high proportion occurring just after restrictions come into play at 6:00 AM and again at 4:00 PM, and just before restrictions are removed at 9:00 AM and 7:00 PM. In the case of Alameda 580, preferential lane restrictions begin officially on Monday at 6:00 AM and are legally in force until Friday at 6:00 PM. However, an unusually high proportion of violations occurs between 6:00 PM and 7:00 PM every weekday, suggesting that a large number of drivers wrongly interpret the operating hours to be 6:00 AM to 6:00 PM, Monday through Friday. In this case, a significant proportion of peak period violations could 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, while 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.

The limited number of projects examined provides little insight into the question of whether all-day operation is preferable to peak period operation for mainline HOV lanes. The opening of such lanes to all day operations is not likely to increase either violation level or enforcement requirements appreciably, and may simplify signing problems and reduce confusion during the changeover times. At the same time, it is impossible to enforce occupancy restrictions after dark, and the additional hours of HOV lane operation at times when there is no time advantage to be gained from using the lane are not likely to encourage many additional carpools.

Refuge Area

Both the San Bernardino Busway and Alameda 580 have adequate refuge areas either on the buffer strips separating the preferential lanes from general traffic or on the median. The absence of such areas on Marin 101 highlights the need for suitable refuge areas.

On Marin 101, the lack of buffers separating the carpool lanes from general traffic, coupled with the narrowness of the lanes themselves and the absence of a median made it necessary for officers to escort violators across heavy traffic to issue citations on the shoulder of the roadway. Patrol cars had particular difficulty accomplishing the maneuvers needed to pursue and apprehend violators under these circumstances, so that motorcycle patrols had to be used for special enforcement. In this case, then, certain project design

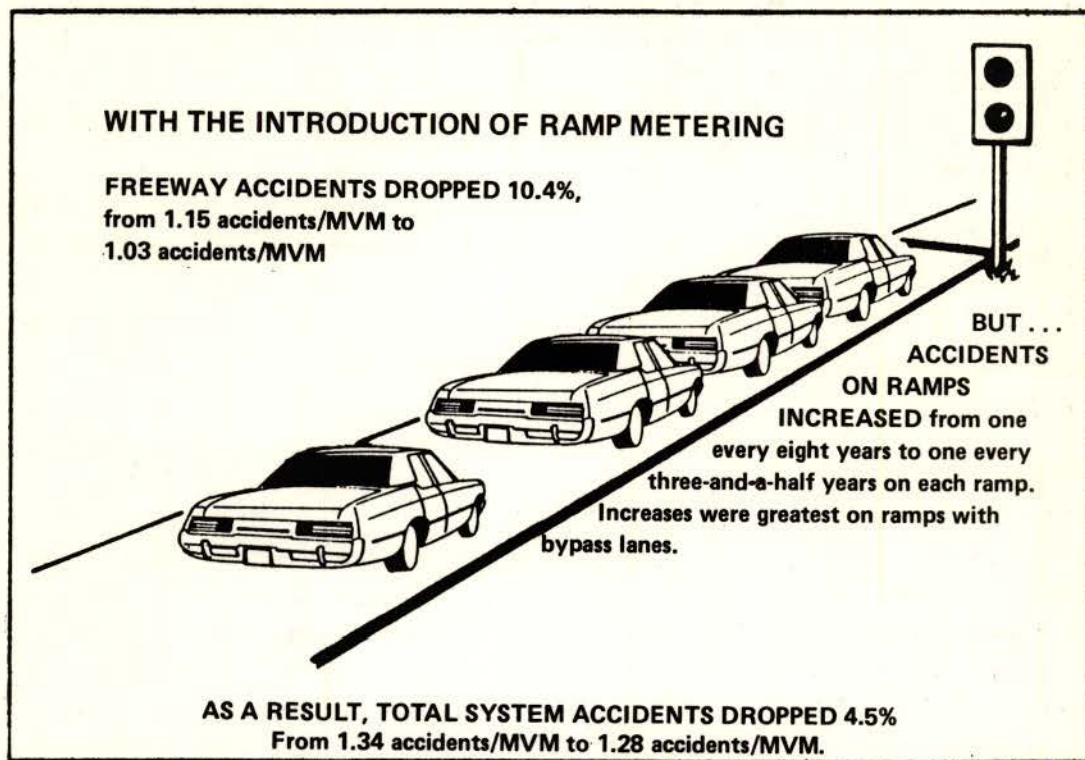
features made enforcement difficult and required the use of special officers. Surveys showed, moreover, that the need to issue tickets on the shoulder of the roadway at a location well removed from the preferential lane left many drivers unaware that the lane restrictions were actually being enforced.

Lane Separation

By the close of the study, it appeared that the degree of separation between general traffic lanes and the preferential lanes had a measurable impact on violation rates. Lane violation rates were lowest (3% to 4%) on the lightly-enforced western section of the San Bernardino Busway where a physical-barrier made lane switching impossible, and considerably higher (27%) on heavily-enforced Marin 101, where there was no separation whatever between preferential and general lanes. Violation rates were also low (7%) on the buffer-separated portion of the San Bernardino Busway. Violation rates were highest (36%) on the lightly-enforced buffer-separated lanes of the controversial Alameda 580 project.

SAFETY IMPLICATIONS

METERED RAMPS AND BYPASS LANES



For a sample of freeways under ramp control, accident rates on the freeways alone dropped 10.4%, from 1.15 accidents/MVM to 1.03 accidents/MVM following the introduction of ramp metering. At the same time, accident rates on the ramps themselves increased significantly, nearly tripling during the first year of meter control. Whereas accident rates dropped in subsequent years on ramps without bypass lanes, accidents on bypass ramps showed no sign of decline. Accident rates appeared to be highest and most persistent on ramps with high violation rates.

Even with the increases associated with metering and bypass lanes, the annual incidence of ramp accidents was relatively infrequent, averaging one accident every three years on a ramp with a bypass, and one accident every four years on a metered ramp without a bypass. This increase was not sufficient to offset the decline in freeway accidents associated with ramp control. Total system accidents after ramp metering amounted to 1.28 accidents/MVM, a decline of 4.5% below pre-metering accident rates.

MAINLINE HOV LANES

SUMMARY OF ACCIDENT RATES ON MAINLINE HOV LANES

PROJECT	MORNING PEAK					EVENING PEAK				
	Before HOV	First Year of Operation		Subsequent Years		Before HOV	First Year of Operation		Subsequent Years	
	ACC/MVM	ACC/MVM	% Increase Over Before Period	ACC/MVM	% Increase Over Before Period	ACC/MVM	ACC/MVM	% Increase Over Before Period	ACC/MVM	% Increase Over Before Period
NON-SEPARATED LANES										
Marin 101	1.71	1.42	-17%	1.04	-39%	4.18	9.26	+122%	6.77	+62%
Santa Monica Freeway	1.36	4.09	+201%	*	*	1.76	5.64	+221%	*	*
SF-Oakland Bay Bridge Toll Plaza	4.86	15.08	+210%	7.58	+56%					
BUFFERED LANES										
Alameda I-580	1.50	0.90	-40%	0.32	-79%	1.67	1.49	-11%	1.18	-29%
San Bernardino Busway (eastern segment)	1.72	1.37	-20%	1.46	-15%	1.24	2.41	+94%	1.69	+36%
PHYSICALLY SEPARATE LANES										
San Bernardino Busway (western segment)	1.15	0.91	-21%	0.82	-29%	2.34	1.82	-22%	1.42	-39%

*Project discontinued after three months

The above table summarizes accident statistics for several mainline HOV projects in California. Accident levels increased dramatically during the first year of operations on those three projects – Marin 101, the Santa Monica Diamond Lanes, and the San Francisco/Oakland Bay Bridge Toll Plaza – where there was no separation between the HOV lane and general traffic lanes. Although accident rates subsequently declined on Marin 101 and the Bay Bridge, these rates remained significantly higher than pre-project levels five years after project implementation.

On the two projects – Alameda 580 and the San Bernardino Busway – where the HOV lane was separated from general traffic either by a buffer lane or physical barrier, there was no upward surge in accident rates during the first year of project implementation. In fact, accident rates declined steadily on all sections of the San Bernardino freeway since the implementation of the Busway. No trends are discernable on Alameda 580, where the relatively low accident levels fluctuate from year to year.

The increases in accident rates accompanying barrier-free preferential lanes raise serious questions regarding the suitability of this design in certain settings. These questions appear to exist whether the lanes are created by reserving an existing lane, as was done on the Santa Monica freeway, or by creating an entirely new lane, as was done in Marin County. Short segments of barrier-free HOV lane operation – as on toll plazas, ramps, and freeway-to-freeway connectors – are not likely to generate accident increases high enough to offset the benefits of the carpool lane itself. Long stretches of barrier-free mainline HOV lanes operating next to stop-and-go traffic, however, can easily cause unacceptable increases in accident rates.

DRIVER ATTITUDES

SURVEY RESULTS

NEXT, SOME QUESTIONS ABOUT THE SPECIAL BYPASS LANES FOR BUSES AND CARPOOLS ON SOME GOLDEN STATE FREEWAY ON-RAMPS:

1. Bypass lanes for buses and carpools with two or more persons have been installed on some Golden State Freeway on-ramps. Have you ever used these lanes? Yes No
2. Have you ever seen the Highway Patrol stopping a driver for using the bus/carpool lane without the proper number of occupants? Yes No
3. Have you ever received a ticket or verbal warning from the Highway Patrol for using the bus/carpool lane illegally? Yes No
4. What percentage of the drivers in the bus/carpool lane would you estimate use the lane illegally? _____ %
5. Do you think that drivers using the bus/carpool lane illegally are ticketed by the Highway Patrol?
 Always Frequently Sometimes Infrequently Never
6. How do you think the use of the bus/carpool lane by non-carpoolers is a
 Minor problem No problem

Surveys mailed to a sample of single drivers, carpoolers, and carpool lane violators on 13 sample projects before and after special enforcement activities led to the following conclusions regarding driver attitudes.

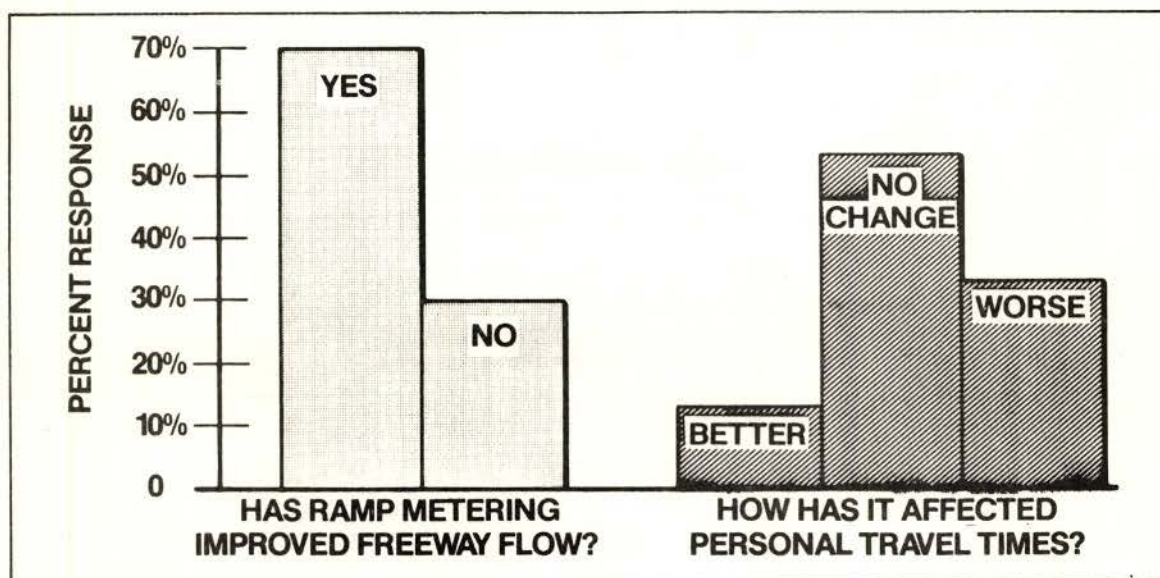
General Attitudes:

- *Although the differences between violators, carpoolers and general users on a particular project are few and generally predictable, there are major differences separating the attitudes and perceptions of users of individual projects. This was especially true on the mainline HOV lanes, with all classes of drivers on the controversial Alameda 580 project viewing the preferential lanes unfavorably, while drivers using Marin 101, the San Francisco/Oakland Bay Bridge, and the San Bernardino Busway were generally more tolerant of HOV projects – relatively few drivers on these three 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 Los Angeles drivers.*

Perceptions of Enforcement:

- *Drivers are significantly more aware of in-place, in-view enforcement than of enforcement requiring pursuit and ticketing on freeway shoulders.* This distinction was particularly evident before special enforcement activities were initiated. On the San Bernardino Busway, where violators are usually apprehended and ticketed in the buffer lane in full view of passing motorists, only 13% 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 issuing tickets, 22% of all respondents reported that they had never seen an occupancy citation issued. On one San Diego ramp with an ample refuge area where CHP officers could stand and wave over violators in full view of other drivers, 25% of all respondents reported they had never seen a citation issued for illegal use of the carpool lane. On a nearby ramp with a scanty refuge area that forces officers to pursue violators and issue tickets some distance from the ramp itself, the corresponding percentage was 70%.
- *Although special enforcement activities significantly improved driver awareness of enforcement on the surveyed projects, a surprisingly high percentage of drivers using ramps with bypass lanes remained oblivious to the presence of enforcement.* After three waves of special enforcement, between 15% and 45% of the drivers on the sample ramps reported that they had *never* seen a driver ticketed for using the bypass lanes illegally. Over two-thirds of all drivers surveyed felt that enforcement levels "stayed about the same" during the year of special enforcement.
- *Drivers themselves perceive a need for more enforcement.* Only about 10% of the drivers interviewed prior to the first wave of enforcement felt that current enforcement levels were sufficient. This was uniformly true on all projects except Alameda 580, where 33% of the respondents felt that there was no need for the CHP to enforce more often.

PERCEPTIONS OF RAMP METERING (LOS ANGELES)



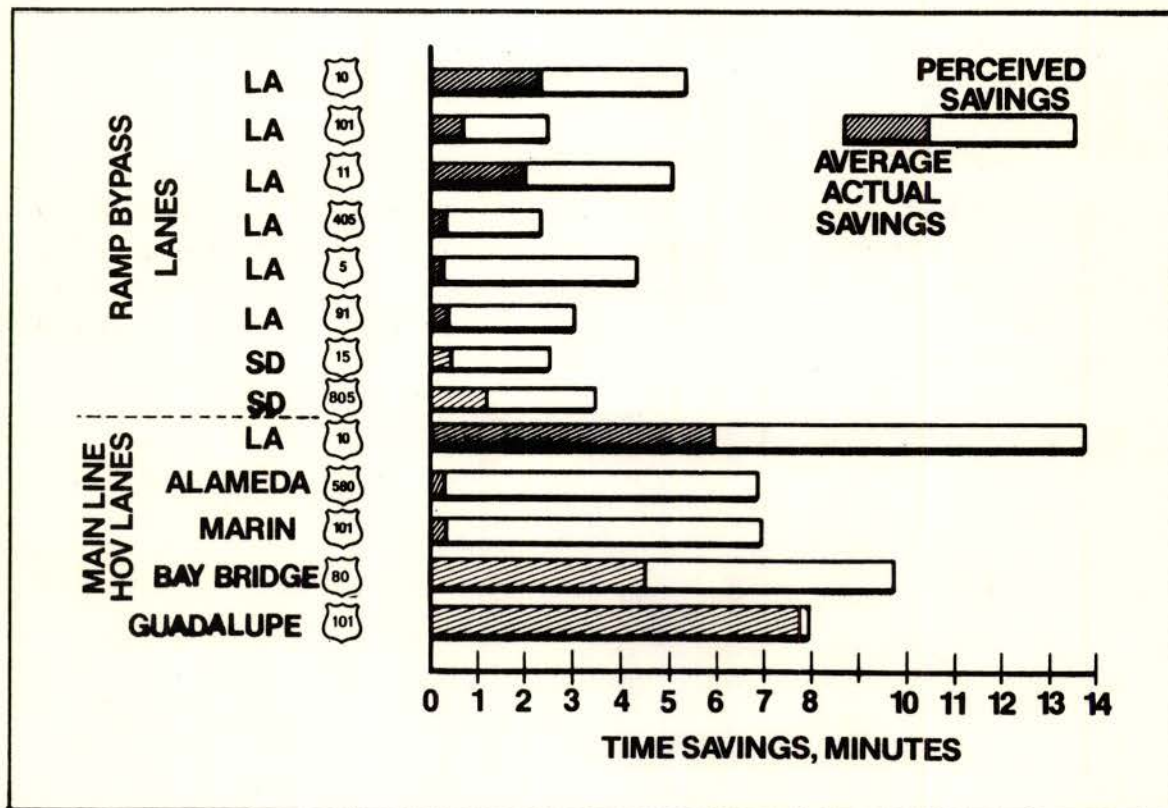
Perceptions of Ramp Metering:

- *Ramp users have mixed feelings regarding the benefits of ramp metering.* While over two-thirds of all drivers feel that metering has improved flow, under 21% feel that it has shortened their individual trip time.

Perceptions of Violations:

- *Drivers tended to overestimate low violation rates and underestimate high violation rates.* While drivers appeared to be sensitive to major improvements in the violation picture, they are not likely to detect changes in the range below a 25% lane violation rate (or a 6.5% ramp violation rate).
- *Most drivers feel that HOV lane violations are a minor problem.* Drivers on the San Bernardino Busway and Guadalupe Expressway felt that violations represented a more serious problem than did drivers on other projects, while Alameda 580 drivers were less concerned than other drivers about the presence of violators. Forty-three percent of the Alameda 580 respondents felt that violators were no problem whatsoever, presumably reflecting the adverse media publicity and public hostility directed toward that project.

ACTUAL AND PERCEIVED HOV LANE TIME SAVINGS



Perceived Time Savings:

- *Violators, carpoolers, and general drivers alike greatly over-estimate the average time savings afforded by HOV lanes.* This tendency to perceive greater time savings in the carpool lane undoubtedly makes the carpool lanes appear more attractive to drivers than to statisticians comparing raw numbers, and 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.

DRIVING RECORDS

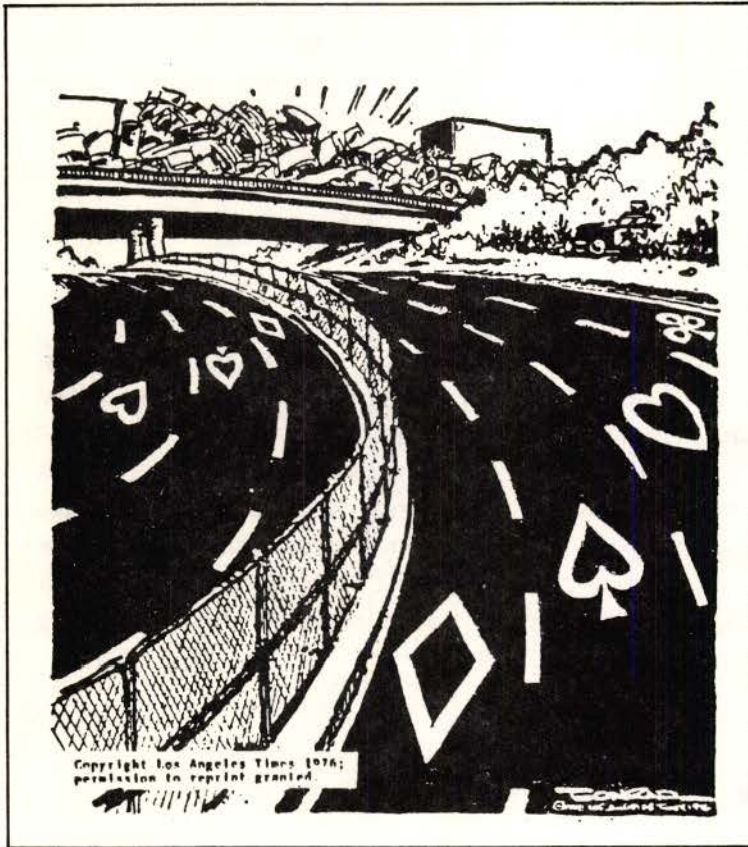
HOV lane violators are likely to have poorer overall driving records than non-violators. An examination of driver records on mainline freeway lanes, bridges, and other HOV projects serving drivers from a wide range of geographic areas showed that HOV lane violators *on these projects* had significantly worse driving records than non-violators. On ramp-bypass lanes serving narrowly circumscribed geographic areas, however, few differences were found between the driving records of violators and non-violators using a particular ramp. Nonetheless, comparisons among different ramps showed a strong correlation between the records of all drivers using the ramp and the ramp violation rate: the worse the driving records, the higher the ramp violation rate.

REPEAT VIOLATIONS

The incidence of repeat violations over short periods is relatively low, suggesting that HOV lane violation rates tend to reflect the actions of a large number of drivers transgressing at infrequent intervals, rather than the day-to-day actions of a small group of repeaters. There are, however, a small group of persistent repeaters on certain projects who managed to remain undaunted by the first year of special enforcement.

PUBLIC INFORMATION

MEDIA COVERAGE



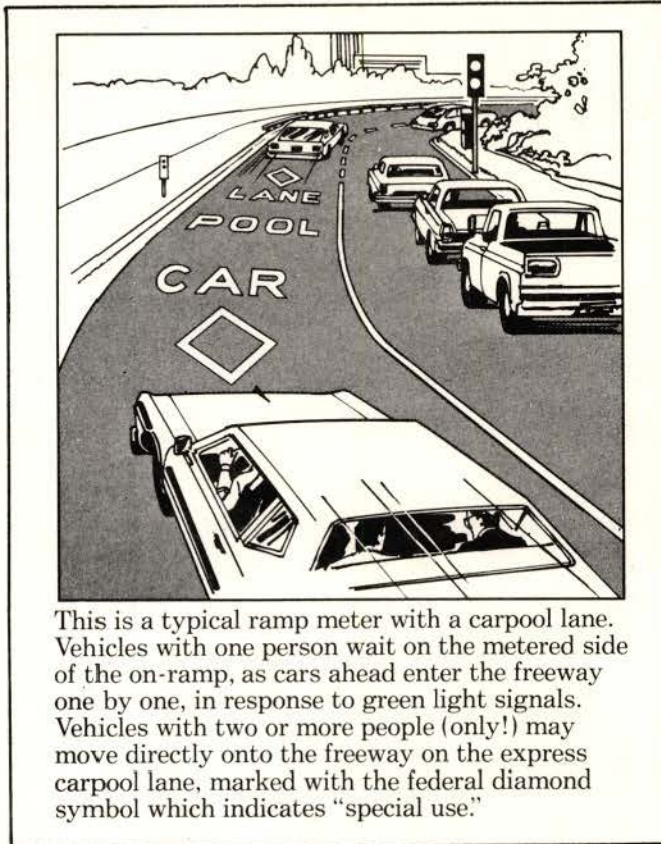
Media coverage of California's HOV projects has tended to be sporadic and generally negative. Negative coverage has peaked during election years and has tended to focus on individual projects, rather than the concept of preferential lanes. In Los Angeles, the Santa Monica Freeway Diamond Lanes were mauled by the media (see cartoon on left), while the San Bernardino Busway, further east on the same Interstate route, has generally been treated fairly and favorably. In the San Francisco Bay Area, Alameda 580 is the focus of predominantly negative press coverage and hostile public opinion, while Marin 101 goes virtually unnoticed and the Bay Bridge toll plaza receives moderately favorable coverage.

While it is impossible to quantify the impact of media coverage and public attitudes on violation rates, it is worth noting that the two California HOV projects receiving the most favorable press notices, the San Bernardino Busway and the San Francisco/Oakland Bay Bridge, have the lowest lane violation rates of all the projects included in this study. On the other hand, if media popularity were the sole criteria governing HOV lane compliance, the Santa Monica Diamond Lanes would have been packed bumper-to-bumper with violators. As it was, lane violation rates on this manifestly unpopular project fluctuated between 10% and 20%, well below the levels recorded on ramp bypass lanes, Marin 101, and Alameda 580.

EDUCATION CAMPAIGNS

Education campaigns aimed at instructing the public regarding HOV lanes make use of many channels, including news releases, media campaigns, ramp and freeway handouts, driver education courses, public speeches, mailed brochures, freeway signs, and the drivers handbook published by the Department of Motor Vehicles. These campaigns tend to be concentrated at the beginning of a project to announce the opening date, explain the purpose of the project, and outline proper use of the new facility (see inset at right).

As with media coverage, it is difficult to gauge the impact of education campaigns on violations. An informal poll of violators taken by CHP officers revealed that relatively few apprehended violators (15% of those surveyed) pleaded ignorance of the law, suggesting that existing education programs have at least made non-carpoolers aware of the illegality of using the lanes. A previous study by CALTRANS concluded that freeway handouts had little impact on violation rates. As part of the current study, it was determined that a two-month radio and TV campaign using public service announcements had no impact on ramp violation rates in the San Diego area. While effective public information programs are essential at the time a project is introduced, and may increase public acceptance during the project's life, there is no evidence to date that they are able to affect violation rates.



This is a typical ramp meter with a carpool lane. Vehicles with one person wait on the metered side of the on-ramp, as cars ahead enter the freeway one by one, in response to green light signals. Vehicles with two or more people (only!) may move directly onto the freeway on the express carpool lane, marked with the federal diamond symbol which indicates "special use."

PROPOSED ENFORCEMENT PROGRAM

A consideration of the effects of different enforcement options and design features on HOV project violation rates, and the resulting effect of violations on freeway performance, safety, and public attitudes, has led to the development of a proposed enforcement program for HOV projects on California's freeways. The proposed program has been designed to keep both the costs of enforcement and the resulting violation rates within reasonable bounds.

RAMP METER BYPASS LANES

The Question of Tolerable Violation Rates

The task of keeping violation rates within reasonable bounds implies an ability to determine a "tolerable" or "acceptable" violation rate. Criteria for establishing tolerable ramp violation rates would include safety, freeway operations, public attitudes, legal integrity, and practicality. This study has provided insights into the impact of violations on several of these important criteria.

- *Safety.* Less than twenty percent of the drivers using ramp bypass lanes illegally do so through maneuvering which presents a direct safety hazard to other drivers. However, there is some statistical evidence that accident levels are significantly higher on ramps with high violation rates. Furthermore, increased violations reduce the effectiveness of the ramp metering system, and tend to nullify the freeway accident reductions resulting from entry control (see freeway operations discussion below).
- *Freeway Operations.* By using bypass lanes illegally, all violators threaten the time savings, accident relief, and other benefits obtainable through metered ramp control. For any particular freeway, the impact of violations on freeway flow will depend on roadway characteristics, the number of ramps provided with bypass lanes, and the metering strategy selected. A sensitivity analysis of a single freeway, however, suggests that ramp violations can have a disproportionate impact on freeway flow. Violation rates of 20% on the sample freeway brought about a 34% reduction in passenger time savings. Violation rates below 10% had a less pronounced impact.
- *Public Attitudes.* The majority of the public regard ramp violations as a minor problem and tend to overestimate low violation rates and underestimate high violation rates. Drivers are not likely to be sensitive to changes in ramp violation rates below the 6.5% range. Law enforcement agencies should keep an open ear for public complaints about violation rates, however, and respond with special enforcement when such complaints are aired.

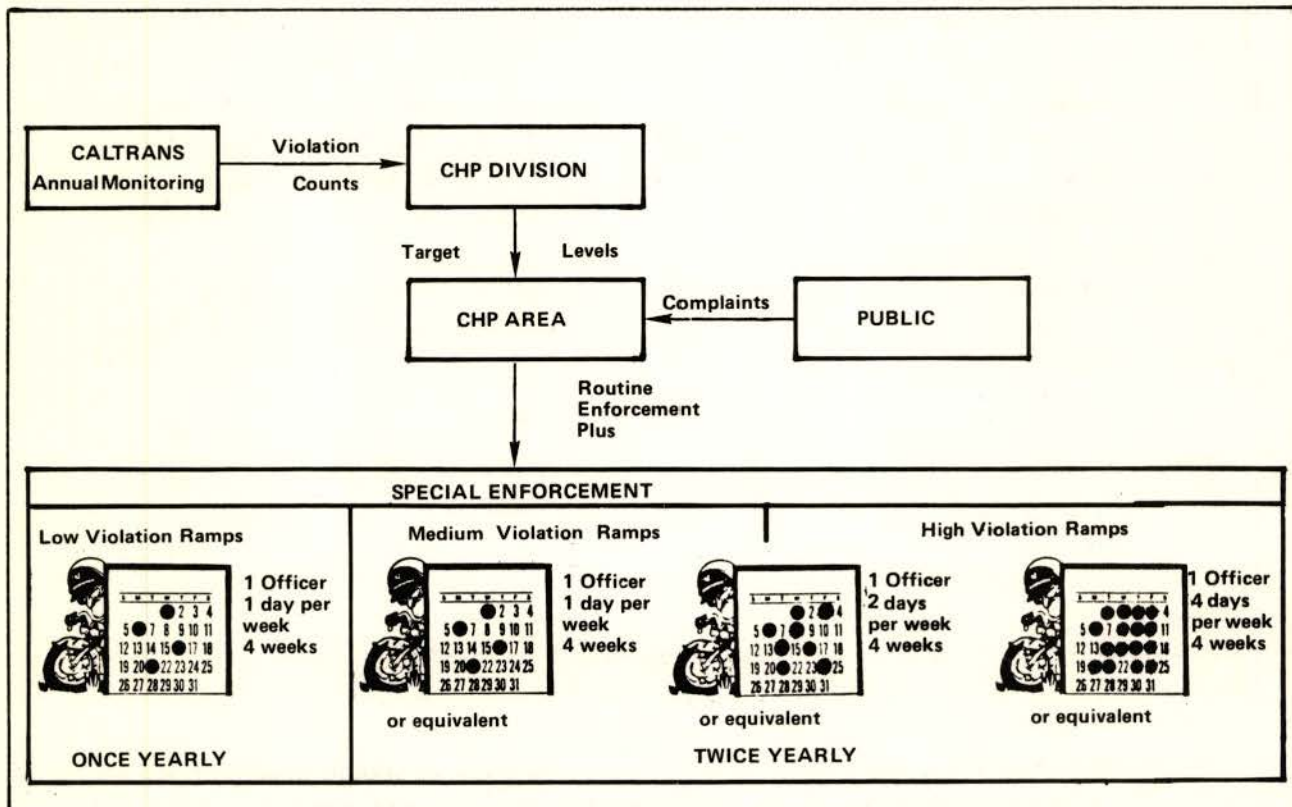
- *Practicality.* It is virtually impossible to drive ramp violation rates significantly below 5%, even with relatively heavy levels of enforcement. These violation rates should definitely be tolerated, and in fact, metering strategies should be designed to accommodate a 5% violation rate.

In the light of these conditions, a proposed enforcement program has been designed with the aim of:

- Reducing violations dramatically on ramps with violation rates over 12% (particularly on ramps with violation rates in excess of 20%).
- Controlling violation rates and achieving further reductions on ramps with violation rates between 6.5% and 12%.
- Maintaining violation levels on low-violation ramps (ramps with violation rates below 6.5%) through a program of routine enforcement and a minimum amount of special enforcement.

Proposed Program

OVERVIEW OF PROPOSED RAMP ENFORCEMENT PROGRAM



The proposed program combines the annual monitoring of violations with scheduled applications of special enforcement interspersed with long stretches of routine enforcement.

- Ramps with medium and high violation rates require twice-yearly applications of four-week periods of special enforcement.
- Ramps with low violation rates (6.5% or lower) will receive relatively low levels of special enforcement once a year.
- Newly-opened bypass lanes shall receive four weeks of special enforcement at the levels recommended for ramps with medium and high violations during the first month of operation.

The proposed program will require the following commitments of officer time:

Ramp Violation Rate	Routine Enforcement (Hours/Year)	Special Enforcement (Hours/Year)	Total (Hours/Year)
Low (< 6.5%)	6	16	22
Medium	7	48	55
High (> 12%)	48	96	144

The enforcement levels recommended on ramps with medium and high violation rates are analogous to those which proved effective in reducing violation rates on comparable ramps during the current study. As the proposed enforcement program progresses, it is anticipated that more and more ramps will be shifted into the "low violation" category, where they will require minimum attention.

Program Costs

While routine ramp enforcement activities can easily be accomplished in concert with other patrol duties, special ramp enforcement requires the dedication of one or two officers to a single ramp for the full metering period. The personnel requirements imposed by the special ramp enforcement program may be met either by offering overtime duty to existing personnel, or by adding personnel to the morning and evening shifts. These two options have markedly different cost implications. In the first case, existing officers must be paid an overtime premium. In the second case, new officers must be hired for eight hours per day to accomplish duties which consume, at most, four hours. The combined average cost of special and routine enforcement under each option is listed below for ramps with low, medium, and high violation rates:

ANNUAL ENFORCEMENT COST PER RAMP (Special and Routine)		
Ramp Violation Rate	Overtime Option	New Personnel
Low (<6.5%)	\$502	\$729
Medium	\$1273	\$1955
High (>12%)	\$3306	\$4669

On the basis of these average rates, the first-year costs of the proposed enforcement program in those CHP Divisions having ramp meter bypass lanes are listed below:

TOTAL ANNUAL RAMP ENFORCEMENT COSTS		
DIVISION	Overtime Option	New Personnel
Golden Gate (San Francisco Metro Area)	\$ 1,775	\$ 2,683
Southern (Los Angeles Metro Area)	172,205	252,577
Border (Orange County & San Diego)	63,474	92,535

These costs amount to an average of \$1,365 per ramp if overtime enforcement is used, and \$2,000 per ramp if new personnel are hired.

Operational Benefits and Costs

The out-of-pocket costs of the proposed enforcement program are roughly commensurate with the societal costs incurred in delays and increased freeway accidents if violations are not controlled. An overview of the average costs and benefits associated with a single metered ramp/bypass lane combination appears on the following page.

**AVERAGE BENEFITS AND COSTS PER RAMP
METERED RAMP/BYPASS COMBINATION**

INITIAL INVESTMENT

\$27,000 (ramp meter)
4,000 (bypass lane)

TOTAL INVESTMENT:

\$31,000

AVERAGE ANNUAL COSTS:

\$1,500 (operations)
3,000 (maintenance)
235 (power)
481 (increased ramp accidents)
\$336 to \$2,013
(traffic disruption resulting
from enforcement)
\$502 to \$4,669
(out-of-pocket
enforcement costs)

AVERAGE ANNUAL BENEFITS:

\$9,255 (improved travel times)
815 (reduced freeway accidents)
717 (priority entry time savings)
\$1,577n (savings per new carpool formed)

TOTAL ANNUAL COSTS:

Violation Rate	(Overtime)	(New Personnel)
Low	\$ 6,054	\$ 6,281
Medium	7,495	8,177
High	10,535	11,898

TOTAL ANNUAL BENEFITS:

\$10,787 + \$1,577n
(where n = number of new
carpools formed)

These costs and benefits reflect average values which assume that all ramps have an equivalent impact on freeway flow. This is not the case, and it is possible that a low level of violations on a few critically positioned ramps can negate most of the positive benefits of ramp metering.

Even if a bypass lane generates no additional carpools, the average annual benefits from installing a ramp meter and bypass lane comfortably exceed the average annual costs of ramp operations and enforcement on all but high-violation ramps. Although the effectiveness of ramp bypass lanes in encouraging the formation of new carpools is not well understood, even a modest degree of success in this area will generate enough benefits to offset both the cost of enforcement and the initial investment in the average bypass lane.

MAINLINE HOV LANES

The Question of Tolerable Violation Rates

As in the case of ramp meter bypass lanes, questions of safety, freeway operations, and public attitudes have been explored in attempting to define a "tolerable" violation rate for mainline HOV lanes.

- *Safety.* Although it is impossible to correlate accident rates with violation rates on any of the mainline projects, the practice of weaving illegally in and out of a mainline lane creates a direct safety hazard. Unsafe weaving has been and should continue to be the primary focus of officers assigned to HOV lane enforcement.
- *Freeway Operations.* The practical capacity of a mainline HOV lane is estimated to be 1,400 vehicles per hour. Except for a one-hour period during the morning peak on the San Bernardino Busway, existing violation rates could increase substantially on all California mainline projects without substantially affecting flow in the carpool lane.

Violators do not improve general traffic conditions appreciably by leaving the mainline flow to enter the HOV lane. During congested periods, latent demand easily replaces the small number of violators drawn off into the carpool lanes. At less congested times, the potential for improvement is minimal.

- *Public Attitudes.* Even on Alameda 580, where public sentiment runs heavily against the HOV lane, most freeway users still feel that the use of the HOV lane by violators is at least a minor problem. Drivers tend to overestimate violation rates on most mainline projects.

On the San Bernardino Busway, the "tolerable" lane violation rate is strictly defined by operational considerations to be 16% or less during the peak morning period. During the other times, the violation rate could be greater from an operational standpoint. Realistically, a tolerable violation rate should be set at 10% or less at all times to keep violations from increasing beyond their present level and prevent the pool of violators from increasing to a point where AM peak period violation rates could hamper Busway operations. For the other projects, the suggested acceptable violation rate is the current normal level. Thus, the main goal of the proposed program is to keep violations from increasing to a point where complaints from the public become common and a mass disobedience of the law becomes apparent.

Proposed Program

The proposed program is summarized below. This program is aimed at maintaining mainline HOV violations at current levels or lower, and represents little change from existing levels on the San Bernardino Busway and San Francisco/Oakland Bay Bridge. On Alameda 580, a small increase in special enforcement is suggested, while Marin 101 could probably be enforced less without incurring adverse effects.

**PROPOSED ENFORCEMENT PROGRAM
MAINLINE HOV LANES AND THE SAN FRANCISCO/OAKLAND BAY BRIDGE**

Route	PERSON HOURS/YEAR			Total Cost
	Routine Enforcement	Special Enforcement	Total Hours	
Marin 101	negligible	4800	4800	\$111,600 (overtime) to \$180,000 (new personnel)
Alameda 580	384	64	448	\$ 10,070
San Bernardino Busway	1920	448	2368	\$ 53,328
SF/Oakland Bay Bridge	120	256	376	\$ 8,628

As in the case of ramp meter bypass lanes, CALTRANS should monitor violation rates at least once annually, with San Bernardino Busway rates monitored quarterly.

On Marin 101, routine enforcement is negligible and special enforcement occurs daily at levels that are probably higher than necessary. If future CALTRANS counts show no increase in violations, the number of motorcycle officers assigned to special enforcement in the evening should be cut from four to two.

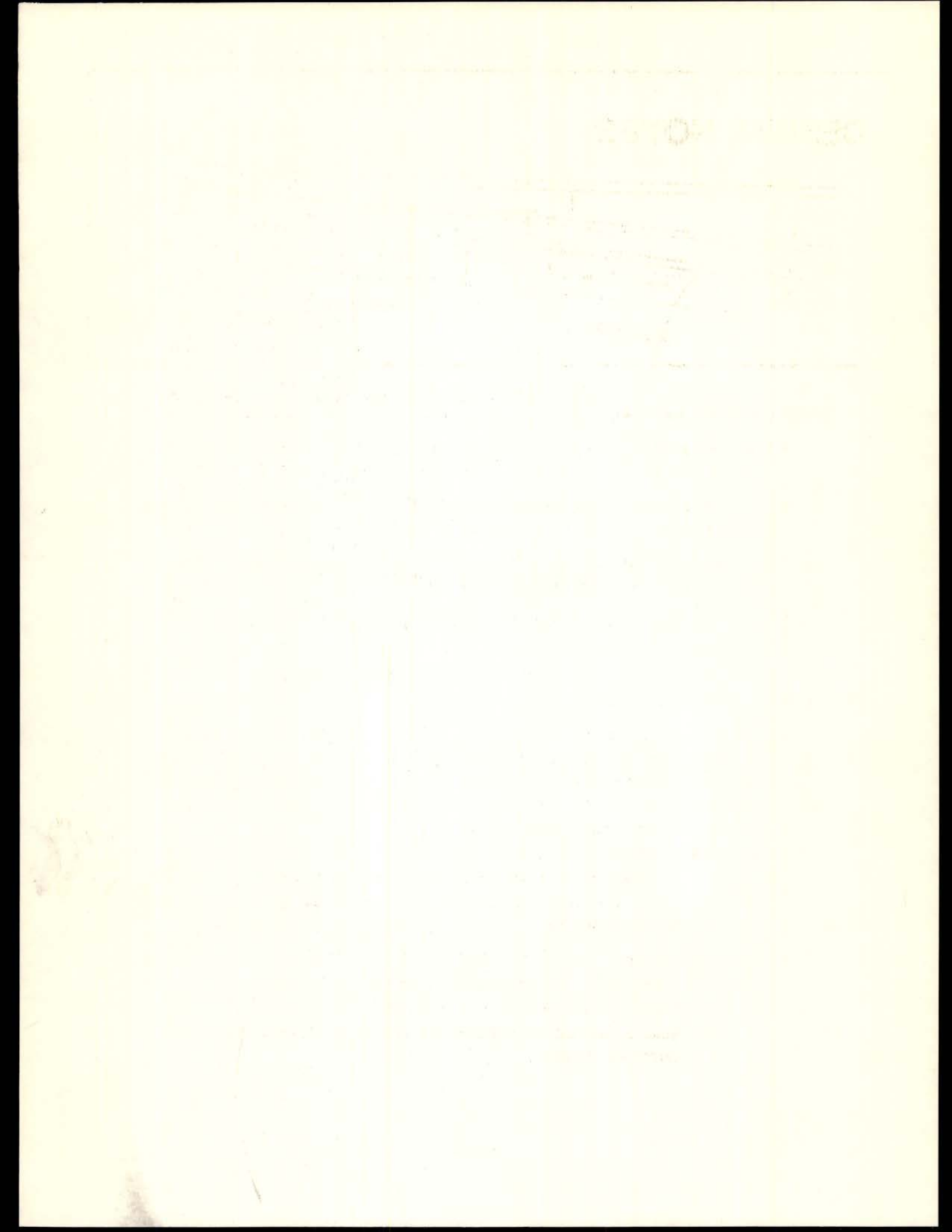
On Alameda 580, two two-week waves of special enforcement are recommended each year, with one direction of flow enforced during each wave.

On the San Bernardino Busway, two four-week waves of special enforcement are recommended each year. Special enforcement should concentrate on the morning peak, especially during the period between 7:00 and 8:00 AM.

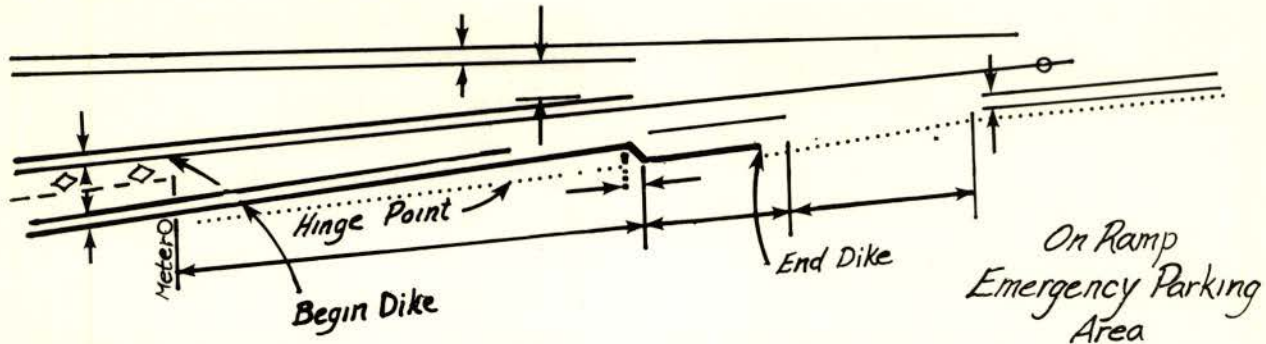
Since short, intense bursts of enforcement appear to be most effective on the San Francisco/Oakland Bay Bridge, four one-week periods of heavy enforcement are proposed each year.

DESIGN AND ENFORCEMENT NOTES

The following pages summarize key study findings of primary interest to agencies charged with the design and enforcement of HOV projects.



DESIGN NOTES



GENERAL OBSERVATIONS

- *Collaboration* between design and enforcement agencies is necessary from project inception.
- *Adequate refuge areas* are essential for the safe and efficient enforcement of all HOV projects.
- *Proper signing and striping* is necessary to give drivers a clear understanding of HOV lane use and comply with legal requirements.
- *Advance Publicity* must advertise all aspects of a project at appropriate levels.

RAMP METER BYPASS LANES

- *Ramp Selection.* So long as major structural modifications are not required, even a modest degree of success in encouraging new carpools will generate enough benefits to offset both the cost of enforcement and the average initial investment in a bypass lane. However, bypass lanes should be avoided where
 - Ramp storage problems exist;
 - Significant numbers of turning vehicles can be trapped in the carpool lane;
 - Relatively low levels of violations can threaten the metering system; or
 - Major structural modifications cause bypass lane costs to outweigh potential benefits.
- *Metering Strategy.*
 - Design rates should accommodate a 5% ramp violation rate;
 - Faster metering rates lead to somewhat lower violation levels;
 - Since drivers will overestimate delays, even short waits provide some carpooling incentive.

- *Ramp Layout.*
 - Enforcing officers *must* have a safe and suitable vantage point and an adequate shoulder area beyond the meter.
 - If possible, the refuge area should be out of the line of sight of potential violators and shielded from the view of motorists on the freeway itself. Unlike the refuge area itself, however, neither of these characteristics is essential to effective enforcement.
- *Signing and Striping.*
 - Bold striping is initially effective in discouraging violations, but its impact diminishes with time.
 - Delineators separating the bypass lane from general traffic are costly and ineffective.

MAINLINE HOV LANES

- *Hours of Operation.*

Proper hours of operation must be determined individually for each mainline HOV project. Twenty-four hour operation simplifies signing problems and eliminates confusion and increased violations at changeover times without increasing enforcement requirements appreciably. However, it is impossible to enforce occupancy restrictions after dark, and operation during off-peak hours when there is no time advantage to be gained from lane use is not likely to encourage many additional carpools.
- *Refuge Areas.*

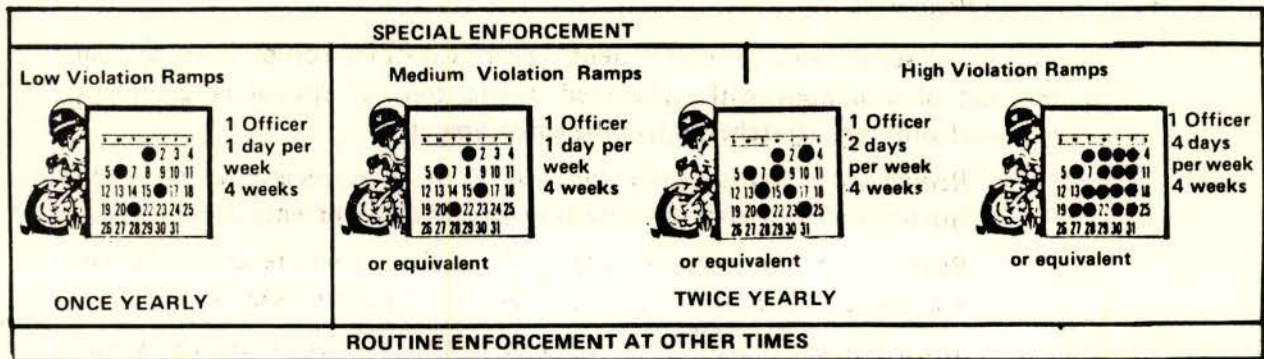
Adequate refuge areas must be provided adjacent to the HOV lane, either on a buffer strip or a median. When violators must be escorted across several lanes of traffic, enforcement is more hazardous, more time consuming, less noticeable to carpools and violators, and less effective.
- *Lane Separation.*

Mainline HOV lanes should generally be separated from general traffic by a buffer shoulder or physical barrier. Without a separation, violations and accidents are likely to be significantly higher.

SAFETY CONCERNS

Although accident rates on ramps increased significantly with the introduction of ramp meters and bypass lanes, the total number of ramp accidents remained relatively small, and did not offset the decline in freeway accidents associated with ramp control. In general, short segments of barrier-free HOV lane operation — as on toll plazas, ramps, and freeway interchanges — are not likely to generate accident increases high enough to offset the benefits of the carpool lane itself. Long stretches of barrier-free mainline HOV lanes operating next to stop-and-go traffic, however, can easily cause major increases in accident rates. The increases in accident rates accompanying barrier-free mainline HOV lanes raise serious questions regarding the suitability of this design in certain settings. These questions appear to exist whether the lanes are created by reserving an existing lane, as was done on the Santa Monica freeway, or by creating an entirely new lane, as was done in Marin County.

ENFORCEMENT NOTES



GENERAL OBSERVATIONS

- *Enforcement is essential* to the success of HOV strategies.
- *A combination of routine and special enforcement* will generally be required for the effective control of violations.
- *Cooperation* between enforcement and operating agencies is necessary both for smooth operations and for effective enforcement.
- *Court officials should be thoroughly briefed* prior to project opening.

RAMP METER BYPASS LANES

- *Need for Selective Enforcement.*
 - *Routine enforcement alone proved ineffective* in controlling ramp violation rates, even when levels were increased by requiring officers to spend ten minutes of each day on ramp enforcement.
 - *Special enforcement efforts nearly always reduce violations*, particularly on ramps with high violation rates.
 - *Special enforcement on selected ramps improved the effectiveness of routine enforcement* on nearby ramps.

- *Proposed Program.*

A program of selective ramp enforcement is proposed which combines the annual monitoring of violations with scheduled applications of special enforcement interspersed with long stretches of routine enforcement.

- *Ramps with medium and high violation rates* receive twice-yearly applications of four-week periods of special enforcement.
- *Ramps with low violation rates (6.5% or lower)* will receive relatively low levels of special enforcement for four successive weeks each year.
- *Newly-opened bypass lanes* will receive four weeks of intense special enforcement during the first month of operation.

- *Program Aims.*

The proposed enforcement levels proved effective in the current study and have been designed to

- Reduce violations dramatically on ramps with violation rates over 12% – particularly on ramps with violation rates in excess of 20%.
- Control violation rates and achieve further reductions on ramps with violation rates between 6.5 and 12%.
- Maintain violation levels on low-violation ramps through routine enforcement and a minimum amount of special enforcement.

The out-of-pocket costs of the proposed program are roughly commensurate with costs incurred in increased congestion and freeway accidents if violations are not controlled.

- *Enforcement Tactics*

- Special enforcement officers should park their vehicles beyond the ramp meter and assume a stationary position to wave violators over to a safe refuge area.
- Although officers standing out of the view of potential violators issued more citations than officers who assumed more visible positions, they had roughly the same impact in reducing violations.
- Enforcement tactics requiring vehicle pursuit were much less efficient than stationary enforcement in generating citations, reducing violations, and providing a cautionary example to other ramp users.
- Where possible, ramps should be enforced out of the view of mainline traffic to avoid disrupting flow on the freeway itself.

- *Enforcement Priorities.*
 - Because violations of the ramp meter itself (by running the red signal) occur much less frequently than occupancy violations and pose less of a threat to freeway performance, officers assigned to special ramp enforcement should concentrate on apprehending occupancy violators.
 - Officers should focus especially on the 20% of occupancy violators who, by weaving, sudden stops, and other evasive actions pose an immediate safety threat.

- *Experimental Findings.*
 - Four waves of special enforcement over 18 months caused the average ramp violation rates on sample ramps to drop from 11.9% to 6.5%.
 - Twelve-week periods of special enforcement were not significantly more effective than four-week periods.
 - Assigning two officers to a specific ramp for a number of days was nearly as effective as assigning a single officer for twice as many days.
 - The immediate decline in violation rates, and the duration of the decline, diminished with repeated applications of special enforcement. The median span of time before violation rates returned at least once to pre-enforcement levels dropped from eight weeks following the first enforcement wave to two weeks following the fourth wave.
 - There was little evidence that higher fines lead to lower HOV lane violation rates.

MAINLINE HOV LANES

- *Proposed Program.*

A program of selective enforcement, with a month of special enforcement undertaken at relatively infrequent intervals, is capable of controlling violation rates on California's mainline HOV lanes, so long as routine enforcement is not neglected during the intervening periods.

 - *Marin 101.* Absence of median makes special motorcycle enforcement necessary. Current level of four units per evening peak could be reduced if violations don't increase.
 - *Alameda 580.* Two 2-week waves of special enforcement are recommended yearly, with one direction of flow enforced during each wave.

- *San Bernardino Busway.* Two 4-week waves of special enforcement are recommended each year, concentrating primarily on the morning peak.
 - *SF/Oakland Bay Bridge.* Four 1-week periods of heavy enforcement are proposed each year.
- *Program Aims*

The proposed program is aimed at maintaining mainline HOV violations at current levels or lower.
 - *Enforcement Strategies and Tactics*
 - Routine and special enforcement units should patrol the lane adjacent to the HOV lane when traffic is relatively free flowing, and assume a stationary position in the buffer lane or median when heavy congestion occurs.
 - To minimize the impact of enforcement on mainline traffic flow, special enforcement officers should
 - avoid bunching together;
 - limit stacking so that no more than two cars are stopped at any time;
 - release cited motorists into the HOV lane; and
 - avoid pursuing violators across several lanes of traffic;
 - Special enforcement during any month can be concentrated in a single peak period, so long as neither peak is neglected in the long run.

TOLERABLE VIOLATION RATES

- *Ramp Meter Bypass Lanes.* Although less than 20% of all violators represent a direct safety hazard, all violators threaten the time savings and accident relief available through metered ramp control. Impacts will vary from ramp to ramp, but ramp violation rates in excess of 12% are likely to have a disproportionately adverse impact on freeway flow and accident levels.
- *Mainline HOV Lanes.* Violators who create immediate safety hazards through unsafe lane changes should be accorded top enforcement priority. In theory, these violators who pose immediate hazard will not cause carpool lane flow to deteriorate until flow rates in the lane approach 1400 vehicles per hour. To keep this from occurring on the San Bernardino Busway, violation rates during the morning peak should not be allowed to exceed 10%. Violation rates on other mainline HOV projects could increase considerably before threatening carpool lane operations, so the suggested acceptable violation rate on these projects has been set at current levels.

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