THE SANTA MONICA FREEWAY DIAMOND LANES: FREEWAY ACCIDENT ANALYSIS

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The Santa Monica Freeway Diamond Lanes, a pair of concurrent-flow preferential freeway lanes for buses and carpools linking the City of Santa Monica, California with the Los Angeles Central Business District (CBD), opened on March 16, 1976, and operated amid much controversy for 21 weeks until the U.S. District Court halted the project. One of the most disturbing aspects of the project was the high incidence of freeway accidents, which increased by a factor of 2.5 times pre-project levels when the barrier-free preferential lanes were operating. This paper tabulates accident levels before, during and after the project; postulates and analyses a number of hypotheses regarding potential accident causes; compares the Santa Monica Freeway accident history with that of other preferential lane projects; and identifies the most likely causes of the increased accident levels. This analysis is part of a broader study of the Diamond Lane Project sponsored by the Urban Mass Transportation Administration's Service & Methods Demonstration program. Factors contributing to the increased accident rate included the distracting effect of increased enforcement activities and the congestion resulting from the removal of freeway lanes from general use. However, it appears that the most significant factor was the pronounced speed differential between the free-flowing traffic in the sparsely-occupied preferential lane and the stop-and-go traffic in congested adjacent lanes, coupled with the frequent lane changes made by vehicles entering and leaving the freeway.The experiment in Santa Monica raises serious questions about the use of barrier-free preferential lanes.

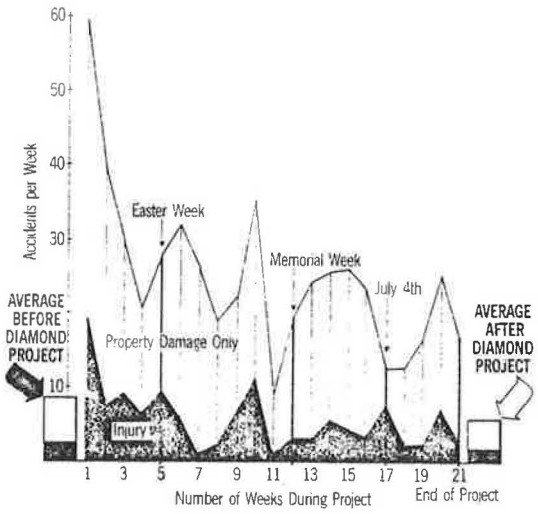
The Santa Monica Freeway, which connects the City of Santa Monica and downtown Los Angeles, is one of the most heavily traveled freeways in the world, and is served by a variety of sophisticated traffic devices, including metered on-ramps with preferential entry provisions at selected locations for two-person carpools, a computerized surveillance system, and centrally-controlled electronic displays. On March 15, 1976, the median lane in each direction of a twelve-mile, eight-lane segment of the Santa Monica Freeway was reserved for the exclusive use of buses and carpools carrying three or more occupants. The reserved lanes, known locally as the Diamond Lanes, operated in each direction during the peak hours of traffic flow. No barriers separated these lanes from the remaining flow of freeway traffic. Implementation of the Diamond Lanes was accompanied by the introduction of a variety of express bus services and the opening of three new Park-and-Ride lots in Western Los Angeles.

The Santa Monica Freeway project marked the first time preferential lanes had been created by taking busy freeway lanes out of existing service and dedicating them to the exclusive use of high-occupancy vehicles. Although the Diamond Lanes entailed no major physical modifications or construction on the freeway itself, they generated considerable physical and emotional dislocation among freeway drivers and other residents of Los Angeles. The first day of operations was disastrous, featuring bumper-to-bumper traffic, long queues at on-ramps, many accidents, outraged drivers, poor press notices and derisive news commentary. As the project progressed, freeway performance improved somewhat and both bus and carpool ridership increased, but accidents remained a problem and the climate of public opinion and media reaction grew more hostile. The preferential lanes operated amid much controversy for 21 weeks until August 9, 1976, when Judge Matthew Byrne of the U.S. District Court in Los Angeles halted the project and ordered additional environmental studies prior to its continuation.

Accident Statistics

Since the first week of operation, when fifty-nine accidents were reported during Diamond Lane operating hours, the total number of reported accidents dropped substantially, with an average of eighteen accidents per week during the last month of the project. Throughout the 21 weeks of the project, 527 accidents were reported during peak operating hours for an average of 25 accidents per week. This number is significantly higher than the average rate experienced prior to the project. Figure 1 (1) plots the average number of accidents occurring per week during the years 1972 through 1975, along with a week-by-week summary of accident levels during the first seven months of 1976. The level of accidents on the Santa Monica Freeway during the Diamond Lane operating hours was more than double the rate experienced during the period immediately preceding the

Figure 1. History of Freeway Accidents During Peak Operating Hours.



project, and more than two and one-half times the average rate experienced during the four years preceding 1976.

Trends Per Million Vehicle-Miles

Since accidents on the Santa Monica Freeway rose at the time that vehicle mileage decreased, the measured increases in accident levels are even more striking when considered in the light of the common index, accidents per million vehicle-miles (MVM). During the operation of the Diamond Lane project, the overall accident rate was 5.1 accidents per MVM. Accidents involving property damage only (PDO) averaged 3.9 accidents per MVM, and injury accidents averaged 1.16 accidents per MVM. The overall accident rate during the Diamond Lane project period was 3.64 times the rate recorded during the same period of the previous year (March 17 to August 12, 1975). This overall rate is biased by the influence of unusually high accidents and unusually low vehicle volumes during the early weeks of the project. As the project progressed, accident levels dropped while vehicle volumes increased, bringing about a steady decline in the accidents/MVM measure, a decline that was still continuing as the project ended. Following the close of the demonstration, accidents dropped below pre-project rates, emphasizing the role of the Diamond Lanes in generating the observed accident increases.

Breakdown By Severity, Time, Direction, Type, And Location

Table 1 (5) compares accident levels on the Santa Monica Freeway by severity, time, direction, type, and location for two time periods: the 21 weeks of the demonstration and a comparable 21-week period in 1975.

The three major categories of freeway accident severity are: (1) fatal; (2) injury; and (3) property damage only (PDO). Historically, few fatal accidents have occurred on the Santa Monica Freeway during peak operating hours--an average of one per year during the few years between 1972 and 1976--and no fatalities occurred during the Diamond Lane project. However, both injury and PDO accidents increased markedly with the

Table 1. Accident Summary for Santa Monica Freeway Before and During Diamond Lane Operation.

	BEFORE		DURING		
	3/17/75 to 8/8/75 21 Weeks 8 Hours/Day		3/15/76 to 8/6/76 21 Weeks 8 Hours/Day Before 6/17 7 Hours/Day After 6/17		
	Total No.	% of Total	Total No.	% of Total	% of 1975
Total Accidents	180	100%	527	100%	293%
Accidents/Week	8.6		25.1		
Severity					
Fatality	0	0%	0	0%	0%
Injury	50	27.8%	120	22.8%	240%
a. Severe		3%	1	0.8%	
b. Other Visible		39%	46	38.3%	
c. Complaint of Pain		58%	73	60.8%	
Property Damage Only	130	72.2%	407	77.2%	313%
Time/Direction					
Eastbound AM	51	28.3%	108	20.5%	212%
Westbound AM	19	10.6%	65	12.3%	342%
Eastbound PM	43	23.9%	178	33.8%	414%
Westbound PM	67	37.2%	176	33.4%	263%
Eastbound	94	52.2%	286	54.3%	304%
Westbound	86	47.8%	241	45.7%	280%
Type of Collision					
Head-on	2	1.1%	2	0.4%	100%
Sideswipe	23	12.8%	47	8.9%	204%
Rear-end	122	67.8%	422	80.1%	346%
Broadside	12	6.7%	9	1.7%	75%
Hit Object	13	7.2%	42	8.0%	323%
Other	8	4.4%	5	0.9%	63%
Lane					
Median	14+	6.9%	24	4.6%	171%
Diamond Lane	55+	27.0%	27	5.1%	49%
No. 2 Lane	29++	14.2%	310	58.8%	534%
No. 3 Lane	29++	14.2%	51	9.7%	88%
No. 4 Lane	68+	33.3%	33	6.3%	49%
Other	9+	4.4%	82	15.6%	911%

+ Prior to the project, more than one location was recorded for each accident when multiple collisions occurred. Hence, the total number of lane locations adds to a total greater than the number of accidents.

++ Prior to the project, accident data did not distinguish between the Number 2 lane and the Number 3 lane. A total of 58 accidents recorded in these median lanes have been split evenly between the two lanes.

implementation of the Diamond Lanes, with injury accidents increasing by a factor of 2.4 over a similar period in 1975 and by a factor of 2.5 over the average level recorded between 1972 and 1976. PDO accidents increased by a factor of 3.1 over the average recorded during the few preceding years.

Injury accidents may be further divided into three subcategories: (a) severe; (b) visible injuries; and (c) complaint of pain. Only one severe accident (slightly less than one percent of all injury accidents) occurred during the Diamond Lane project, while 38% of reported injury accidents entailed other visible injuries, and 61% of injury accidents resulted in complaint of pain. A sampling of injury accidents occurring during 1975 shows a slightly higher incidence of severe accidents (3% of all injury accidents), but statistical tests give no basis for concluding that the Diamond Lanes affected the relative severity of injury accidents on the Santa Monica Freeway.

Almost twice as many accidents occurred during the evening peak as during the morning peak. The dominance of the evening hours coincides with pre-project experience. The greatest relative increase in accidents by time and direction occurred in the eastbound lanes during the evening rush hours. For the corresponding period in 1975, 43 accidents occurred in these lanes during the evening peak. During the evening Diamond Lane operating hours, 178

accidents occurred in this off-peak direction, an increase of 314% over pre-project levels.

Rear-end collisions accounted for 80% of the accidents recorded during Diamond Lane operating hours. During a similar operating period in 1975, rear-end collisions accounted for only 68% of all freeway accidents. Thus, the relative incidence of rear-enders increased significantly during the project, reflecting an increase of stop-and-go conditions in the non-preferential lanes of the freeway.

In addition to the absolute increases in the number of accidents occurring during project implementation, certain changes occurred on the relative pattern of accidents. Perhaps the most notable was the marked increase of accidents in the Number 2 lane adjacent to the Diamond Lane. The number of accidents in the adjacent lane rose from under two accidents per week prior to the project to 14.8 accidents per week during the Diamond Lane operating hours, an increase of more than 13 accidents per week. The average increase in accidents on the entire freeway during project implementation was on the order of 15 accidents per week. Thus, a significant proportion of the overall increase in accidents was concentrated in the Number 2 lane.

Along the length of the project, most accidents occurred on those easternmost sections of the freeway near the CBD, where traffic volumes were highest. In the eastbound lanes, however, the greatest relative increases in accidents occurred farther from the CBD, at the point where cars from the San Diego Freeway entered the flow of traffic. The highest percentage of westbound accidents during both morning and evening hours, before and during the Diamond Lane project, occurred near the CBD, at a point where vehicles from a heavily used collector road and the Harbor Freeway entered the flow of traffic.

Probable Accident Causes

A number of potential causes were identified in an attempt to account for the observed increase in accident levels. These causes stemmed from a variety of factors, including increased CHP presence, increased congestion, the mechanics of Diamond Lane operation, the novelty of the Diamond Lane concept, and exogeneous events. The most prominent of these causes were listed in the form of hypotheses and examined in the light of available data. The remainder of this subsection discusses each of these hypotheses in the light of accident statistics reported during the period of project implementation. Hypotheses:

Accidents were related to increased CHP deployment and enforcement levels. The increased presence of the CHP may have led to increased accident rates for either of two reasons:

A. Minor accidents that previously would have gone unreported were more likely to be reported if more CHP units were present.

B. Increased ticketing rates led to gawking and unexpected slowdowns, causing accidents.

Details of CHP personnel deployment and enforcement activities before and after project implementation may be found in the official evaluation report (1 and 3). During the first week of the project, personnel deployment levels on the Santa Monica Freeway were approximately double pre-project levels. This level was reduced gradually over the demonstration period, so that the average d eployment level over the early weeks of the project was roughly 50% higher than normal. By the thirteenth week of the demonstration, the level of officer deployment approximated that experienced prior to the Diamond Lane project.

In an attempt to discover the extent to which increased CHP deployment and enforcement levels were related to observed accident increases, day-by-day correlations of accidents with both deployment and enforcement levels were undertaken for the period following the implementation of the Diamond Lane project. The results suggest that deployment and enforcement each had some small effect on accident levels, but are inconclusive for determining which effects were greater. The very strong correlation between deployment and enforcement levels makes it difficult to separate the effects mathematically. If overreporting were a significant factor in the accident increase, however, minor (PDO) accidents would have increased at a more rapid rate than more serious injury accidents. This did not occur. In the light of the proportional increases in both major and minor accidents, and the continued high level of accidents once deployment had returned to normal, it appears that any effect of increased CHP presence on Santa Monica Freeway accident levels was more likely to be a result of their ticketing activities than a result of any tendency to overreport minor accidents.

Prior to project implementation, accidents, deployment and enforcement levels were relatively low. Following implementation, accidents increased markedly, decreased, and settled at more than twice pre-project levels. Deployment increased by a factor of approximately 50% during the early weeks of the project and returned to pre-project levels early in the month of June. Enforcement activities, however, increased dramatically with project implementation and continued at levels well in excess of pre-project experience. The number of citations and warnings issued for Diamond Lane and entry ramp violations immediately following project implementation was more than four times the estimated number of citations issued for other traffic violations prior to the project. By the close of the demonstration, the total number of enforcement contacts stemming from illegal use of the Diamond Lane and Freeway on-ramps remained more than double the estimated pre-project level for all traffic violations. Thus, the general pattern followed by enforcement activities before and during project implementation parallels the pattern of accidents. These similar patterns, consisting of a marked increase followed by a decline to a level more than double pre-project levels reinforces the hypothesis that enforcement activities could have contributed to the increased accident level. It is clear from air surveillance traffic reports and observation of Freeway operations that Freeway traffic bunches up in areas in which tickets are being given. This bunching leads to stop-and-go conditions conducive to rear-end accidents.

Analysis suggests that it is unlikely that increased CHP presence on the Santa Monica Freeway led to any significant overreporting of accidents. It appears, however, that the distracting effect of the increased ticketing activities of the CHP may have accounted for some slight portion of the higher accident rate.

Increased accidents are a direct result of increased congestion resulting from the denial of a lane to non-carpoolers. A comparison of accident locations with vehicle volumes along the Freeway reveals the not-unexpected finding that, in general, the heaviest accident locations are found where vehicle volumes are heaviest. The type of accident most prevalent following project implementation--the rear-end collision in the Number 2 lane--would typically accompany increased congestion in that lane. Thus, the observed effects support the congestion hypothesis, although they also support many of the other proposed hypotheses.

No attempt was made to correlate measured congestion by time of day with accidents occurring on that day. The difficulty with this comparison is that ac-

cidents are all too frequently the cause of congestion, and hence will go hand-in-hand with measured congestion.

Although congestion undoubtedly contributed to the increased accident rate, three arguments make it seem unlikely that this factor is the primary cause of the marked increase in accidents:

1. Ramp meters were adjusted to minimize the effects of congestion and permit relatively unobstructed flow on the freeway. Speed runs made in the eastbound direction showed that the adjustments to the metered access ramps restored the non-preferential lanes to a condition of flow approximating that in existence prior to the initiation of ramp metering. Yet the average accident rate on the freeway did not exceed ten accidents per week during the two years prior to the introduction of ramp metering. Congestion increases severe enough to double the accident rate should have been reflected in slower operating speeds.

2. In the early months of 1967, the portion of the Santa Monica Freeway between Arlington and LaBrea Avenues was restriped to add a lane in each direction (4). The added capacity was accompanied by a reported accident drop of 10%, and a 15% decline in the accident rate per million vehicle-miles.

3. With the increase in carpool and bus ridership and the concurrent shifting of some drivers to city streets, the total number of vehicles per hour in each of the non-preferential lanes actually dropped slightly at several locations along the freeway.

Thus, if the demonstration project had simply taken one lane of the freeway out of general use, it is unlikely that the marked increase in accidents would have occurred.

Increased accidents may be traced to the barrier-free operation of the Diamond Lanes at speeds well in excess of the speeds in other lanes. The relative lack of vehicles in the Diamond Lane made it possible for vehicles using the lane to travel at speeds well in excess of the speeds in other, more congested lanes. On the average, Diamond Lane vehicles traveled 12 miles per hour faster than the general freeway traffic. This speed differential is considerably higher than that experienced on other preferential lane projects having no separation between reserved and non-reserved lanes. Observers have proposed that this condition may have led to increased accidents for a number of reasons:

1. The speed differential made safe lane changes more difficult to achieve. Motorists attempting to enter the Diamond Lane had to enter a faster traffic stream from a lower starting speed, while motorists attempting to leave the lane had to slow and attempt to find an opening in slower-moving traffic.

2. The ability to save time by using the Diamond Lanes attracted violators who dodged in and out of the lane unsafely, attempting to stay one jump ahead of the CHP.

3. Drivers in Lane 2 accustomed to the relative absence of vehicles on their left in the Diamond Lane, caused accidents by using the preferential lane as a safety valve to avoid rear-enders in their own lane.

4. The speed differential between the Number 2 lane and the faster adjacent lanes deluded the drivers in the Number 2 lane into believing they could travel faster than conditions in their lane allowed. Further, since traffic conditions were different in adjacent lanes, motorists received no cues from these lanes to indicate how conditions in their own lane were changing.

The most promising sources of information regarding the relative likelihood of the accident causes postulated above are the individual accident reports filed by CHP officers. Examination of these reports provides several insights into the relative incidence of these postulated causes.

The difficulty of changing lanes was often cited as a dangerous aspect of Diamond Lane operation. Analysis of vehicle movements prior to collision shows that the relative percentage of accidents in which at least one of the vehicles was changing lanes remained roughly the same before and during Diamond Lane operation. During Diamond Lane operation, 9% of all vehicles were changing lanes prior to the collision, while the corresponding percentage during a comparable period in 1975 was 9.3%.

Although the absolute number of lane-changing accidents increased markedly during Diamond Lane operation, the increase in other types of accidents was just as great or greater. Significant changes were noted in the relative percentage of accidents in which the vehicles involved were slowing, stopping or standing still prior to collision. These increases reflect the increased incidence of rear-enders in the Number 2 lane and the increased level of stop-and-go traffic in all non-preferential lanes.

Attempts to verify the relative importance of unsafe lane changes as a cause of accidents by tabulating the actions of colliding vehivles involved in the accident tend to be inconclusive. It is not uncommon for a vehicle changing lanes unsafely in congested conditions to escape unscathed while leaving a wave of braking vehicles in its wake that culminates in a rear-end collision well removed from the scene of the initial lane change. In such a case, the drivers involved in the collision are generally aware only of the proximate cause of their accident, and the accident report fails to record the lane change that initiated the chain reaction. Thus, although unsafe lane changes in and out of the Diamond Lane might seem to provide a plausible explanation for the observed increase in rear-end collisions in Lane 2, it is impossible to verify this explanation through a study of individual accident reports.

Early in the Diamond Lane demonstration, CHP officers noted that a few accidents were caused by violators dodging in and out of the preferential lane, attempting to stay one jump ahead of a ticket. Examination of the 51 accidents occurring in the Diamond Lane itself or on the median shows that at least five of these accidents were caused by vehicles carrying fewer than three passengers making unsafe lane changes. In three of these cases, the violators had been observed by the CHP prior to the accident.

One possible cause of accidents in the Diamond Lane itself was the sudden entry into the lane by motorists in Lane 2 trying to use the preferential lane as a safety valve to avoid rear-enders in their own lane. It has been proposed that motorists in Lane 2, used to comparative absence of vehicles on their left in the Diamond Lane, may have moved suddenly into that lane in emergencies, posing a hazard for faster moving traffic in the preferential lane. If this was a serious cause of accidents, it should show up in the reports of CHP officers.

A breakdown of 27 accidents occurring in the Diamond Lane itself during the project shows that 13 of these accidents, or 48%, were caused by vehicles swerving into the lane to avoid trouble in their own lane, and colliding with a Diamond Lane vehicle. An additional nine accidents, or 33%, were caused by unsafe lane changes made by vehicles facing no threat in their own lane. The remaining five Diamond Lane accidents, or 18%, were rear-end collisions between vehicles already in the Diamond Lane.

Vehicles swerving into the Diamond Lane to avoid rear-enders in their own lane were often out of control. In effect, they represented accidents about to happen, and the final nature of the accident depended only on whether there was an oncoming vehicle in the Diamond Lane. On at least 13 occasions, drivers originating in the Number 2 lane spun out to avoid rear-enders and collided with the highway median driver. On at least two other occasions, Diamond Lane drivers were forced into the median by automobiles bailing out of the Number 2 lane to avoid trouble. All of these accidents originated with stop-and-go conditions in the Number 2 lane, even though they were not reported as accidents in that lane.

It seems clear that the combination of high Diamond Lane speeds, when coupled with slow stop-and-go traffic in the non-preferential freeway lanes, contributed to the observed increase in accidents during the Diamond Lane demonstration. The exact extent of this contribution is impossible to determine. Under normal operating conditions, an accident-related slowdown in one lane generally results in a slowdown in all lanes. Given the reserved nature of the Diamond Lane, however, a slowdown in the remaining lanes usually just accentuated the speed differential between the Diamond Lane and the remainder of the freeway traffic. In recognition of the potential danger accompanying the juxtaposition of high Diamond Lane speeds and congested, stop-and-go traffic on the remainder of the freeway, Diamond Lane bus drivers were instructed not to exceed the speed of other freeway traffic by more than 30 miles per hour. There is some evidence, however, that the driver carpooling in the Diamond Lane failed to exercise such prudence when other lanes had slowed to a halt due to accidents or congestion.

The impact of the speed differential on accidents was exacerbated by the need for carpoolers to exit at many points along the freeway. The non-CBD orientation of Los Angeles traffic meant that carpool drivers had to slow and weave their way through stop-and-go traffic to exit at many points along the freeway. Carpoolers responding to the driver survey cited problems exiting from the Diamond Lanes as the greatest single difficulty encountered in using the lanes. Accidents might have been reduced somewhat if more drivers had followed the preferential lane to the end, where merging problems were minimized. The sprawling, multi-centered nature of the Los Angeles area, however, increased the need for carpoolers to merge with slower traffic all along the freeway, thereby increasing the safety hazard associated with the inter-lane speed differential.

Accidents are caused by the novelty of the Diamond Lane itself and the controversy surrounding it. The novelty of the Diamond Lane concept and the controversy surrounding it may have been a source of accidents for several reasons:

1. Driver confusion and experimentation in the early weeks of the project undoubtedly led to higher accident levels.
2. Faster movement in the preferential lanes tended to distract drivers in other lanes, making them more susceptible to accidents.
3. Driver aggravation with the concept may have led to reckless, aggressive driving.

There seems to be little doubt that the surge of accidents during the first two weeks of the project may be traced to the newness of the concept and driver uncertainty regarding the use of the lane. Accident increases have been experienced in the early weeks of other preferential lane projects in which no barrier separates buses and carpools from the remaining lanes of traffic. After initial increases, freeway accidents in both Portland and Miami, where preferential lanes were created by adding a lane to the existing traffic flow, dropped below pre-project levels by the second month of operation.

Drivers of one- and two-passenger automobiles reported a tendency to count the heads appearing in cars whizzing by in the preferential lane. To the extent that the single-occupancy automobile driver persisted in this headcounting, he was less likely to be able to control his own vehicle in an emergency. As drivers became used to the preferential lane, this tendency should have diminished. Although accident rates also diminished as the project continued, there is no sure way to determine the extent to which decreased headcounting accounted for decreased accidents. Specific sources of driver distraction were rarely noted in accident reports, and it is possible that the driver himself may not have been aware of the distraction or may not have wished to admit his inattention to the reporting officer.

Driver frustration and aggravation with the Diamond Lane itself may have contributed to the accident increase. One accident expert noted that the level of frustration would have been especially high among the aggressive drivers used to driving in the Number 1 lane. In testimony before the U.S. Superior Court, Paul O'Shea noted, "...you are taking the aggressive driver and the confident driver, and because he is not entitled to the Diamond Lane, putting him over into the slower traffic, which creates a tremendous frustration." Unquestionably, such frustration did exist, as manifested in the public outcry against the project. However, it is impossible to estimate the extent to which such private frustration may have increased the accident level. Examination of CHP accident reports shows that at least two accidents occurring during Diamond Lane hours may be traced to public frustration with the concept itself. On June 3, drivers opposed to the Diamond Lane concept staged a funeral procession in the lane to protest the lane's existence. The distraction resulting from this demonstration was listed as a contributing factor in two accidents occurring on that day.

Accident explanations not related to the Diamond Lane project. The overall accident level on all Los Angeles freeways has been increasing steadily since the early months of 1974, following the gasoline crisis and the introduction of the 55 m.p.h. speed limit. This increase has been less pronounced during peak operating hours, when there is less chance of a vehicle exceeding the 55 m.p.h. speed limit. On the Santa Monica Freeway during peak operating hours, a linear least-squares regression from January 1974 to the start of the Diamond Lane project shows that the accident level increased by .0215 accidents per week over this period. Extrapolation of this trend would lead one to predict an increase of 0.45 accidents per week during the 21 weeks of the Diamond Lane operation. This represents a small portion of the observed increase of 13.7 accidents per week accompanying the Diamond Lane project, indicating that general trends existing prior to the project had little effect on the accident situation. As noted, moreover, freeway accident rates dropped below pre-project levels following the close of the Diamond Lane demonstration, further discouraging any arguments that causes unrelated to the operation of the Diamond Lanes contributed to the pronounced increase in accidents during project operating hours.

Accident Levels of Other Preferential Lane Projects

In an effort to shed additional light on the

causes behind the accident increase experienced on the Santa Monica Freeway during the Diamond Lane demonstration, accident levels on other barrier-free preferential treatment projects were investigated. Four other projects were selected for comparison: I-95 Freeway, Miami; South Dixie Highway, Miami; Banfield Freeway, Portland; and U.S. 101 Freeway, Marin County, California.

Physical Characteristics

The physical characteristics of each of these projects are summarized below.

I-95 Freeway, Miami. On this 7.5 mile freeway segment, a new barrier-free preferential lane for buses and carpools was created from the median shoulder and opened in December 1975. There are three and four lanes in each direction over the length of the project.

South Dixie Highway, Miami. This is a 5.5 mile segment of highway which runs north to the central business district of Miami. An existing concurrent-flow lane was reserved for carpools (two or more persons) and a contra-flow lane for buses was opened in July 1974. There are three lanes in each direction.

Banfield Freeway, Portland. On this freeway segment (3.2 miles inbound and 1.7 miles outbound), a new barrier-free preferential lane for buses and carpools was created from the median shoulder in December 1975. The roadway has three lanes in each direction overall, with one four-lane segment.

U.S. 101 Freeway, Marin. On U.S. 101 north of the Golden Gate Bridge, a 3.9 mile northbound contra-flow lane has been established. From the Richardson Bay Bridge north, new 3.8 mile northbound and southbound concurrent-flow lanes for buses and carpools were created from the median and shoulder.

On all of these projects except the South Dixie Highway, a new lane was created from the median and/or shoulders; on the South Dixie Highway, as on the Santa Monica Freeway Diamond Lane project, an existing lane was reserved. None of the projects have barriers between the preferential lane and remaining lanes. For the South Dixie Highway project, a carpool is defined as two or more persons; in January 1977, the Miami I-95 project also changed to two-person carpools. In the other three projects, a carpool is defined as three or more persons. All the preferential lanes operate only during peak hours. Speed statistics by lane are available for only three of the projects surveyed. The approximate average speed differentials are 12 miles per hour (mph) on the Santa Monica Freeway, 11 mph on the South Dixie Highway, and 6 mph on Prtland's Banfield Freeway.

Accident Levels

Table 2 summarizes both injury accidents and total accidents per million vehicle-miles for each of the four projects surveyed, in addition to the Santa Monica Freeway Diamond Lanes. Iniury accidents are plotted as a function of time in Figure 2. Because accidents involving property damage only (PDO) are not reported uniformly in all states, reports of injury accidents provide a sounder base for comparing the various projects.

Of the five projects compared, the two with the highest increases in total accidents per million vehicle miles over the "before" period are the Santa Monica Freeway and the South Dixie Highway, with accident rate increases of 264% and 89%, respectively. During both projects, accidents were initially high, but decreased during the succeeding months. Accidents also increased significantly in Marin, rising 82% above pre-project levels during the first years of the project. After initial increases on Portland's Banfield Freeway and Miami I-95, accident rates have varied above and below pre-project averages, but the increases have not been so marked as those of the Santa Monica Freeway, South Dixie Highway, and Marin projects. On Miami I-95, moreover, accident rates appear to have dropped slightly since project implementation. Both the Santa Monica Freeway and South Dixie Highway projects exhibit the highest accident increases and have certain physical and operating characteristics which the other three projects lack: Both were created by removing a lane from existing traffic, and both have a median pull-over area for enforcement use. Thus, enforcement levels on both projects have been high, and violation rates comparatively low. The congestion caused by lane removal and the distracting effects of violators help to account for the increased accident rates in both projects.

Implications of Accident Analysis

Summary of Findings

The creation of the Diamond Lanes on the Santa Monica Freeway through dedication of an existing lane to buses and carpools increased peak hour accidents on the freeway from approximately ten accidents per week to 25 accidents per week. The relative severity of accidents did not change significantly with the project. However, the relative percentage of rear-end accidents occurring in the Number 2 lane rose remarkably from under two accidents per week to 14.8 accidents per week.

A number of potential causes have been identified in an attempt to account for the observed increase in accident levels. These causes stem from a variety of factors, including increased CHP presence, increased congestion, the mechanics of Diamond Lane operation, the novelty of the Diamond Lane concept, and exogenous events. While it is likely that each of these were contributing factors in some instances, in light of the accumulated data, it seems unlikely that certain of the potential causes had a major influence on the accident picture. The increased CHP ticketing activities do not provide a direct explanation for the remarkable increase in accidents in the Number 2 lane, and a correlation of accident and enforcement levels during the demonstration period explains a relatively small proportion of the observed accident variation. Furthermore, equivalent congestion levels existed on portions of the freeway prior to both the 1967 lane enlargement and the introduction of ramp metering without causing pronounced accident levels.

The one potential cause which could not be discounted, and which does in fact appear to account for a large share of the accident increase is the pro-

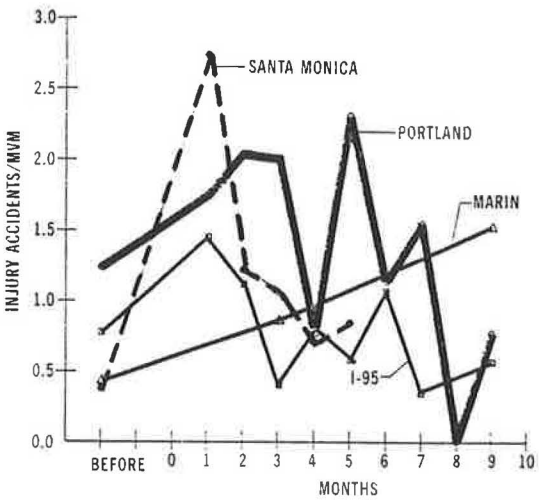
Table 2. Summary of Injury and Total Accidents Per Million Vehicle-Miles.

Project	Period Included in "After" Measurement (Months)	Injury and Fatal Accidents/MVM			Total Accidents/MVM		
		Before	After	% Increase (Decrease)	Before	After	% Increase (Decrease)
Miami I-95	9	0.78	.76	(-2.5%)	3.55	3.44	(-3.1%)
Miami South Dixie Highway	8	NA*	NA*	--	6.4	12.1	89%
Portland	9	1.24	1.37	10.5%	2.48	2.55	2.8%
Marin**	18	0.50	1.31	162%	2.33	4.23	82%
Santa Monica	4	0.40	1.16	190%	1.40	5.10	264%

*NA = data not available.

**Accident data based on the average for three non-continuous six-month periods.

Figure 2. Preferential Lane Project Injury Accidents Per Million Vehicle-Miles.



nounced speed differential resulting from the combination of unhindered traffic in the sparsely occupied preferential lane and congested conditions in the remaining lanes, coupled with the lack of barriers between lanes and the variety of possible destinations along the freeway.

Because of the shortened duration of the project, the effect of Diamond Lane novelty on accident levels can never be known with certainty. The tendency to gawk and count heads of passing carpoolers would certainly have diminished with time. It is not possible, however, to project with confidence the accident level that would have existed following a longer period of operation.

Implications for Planners

Given the nature of the most likely explanations for the increased accident rate, several occurrences could have brought about a decline in accident levels. To the extent that usage of the preferential lane increased with time, the speed differential would decrease as the preferential lane became more crowded and non-preferential lane congestion was reduced by the elimination of defecting carpoolers and bus riders. The reduction of CHP enforcement levels would also work in two ways to reduce the level of accidents: by eliminating the distraction of ticketing, and by permitting more violators to shift to the preferential lanes, thereby cutting the speed differential and easing congestion in the non-preferential lanes. Thus, to some extent, the elimination of either of these two accident sources tends to work against the presumed concept of the preferential lane. As the speed differential is reduced, so also is the inducement to use the lane. Moreover, any decision to relax enforcement must, by encouraging violators, run counter to the philosophy of a lane reserved for high-occupancy vehicles.

The apparent dilemma whereby reduced accidents might be achieved at the cost of lane operating efficiency highlights the delicacy of the control problem faced by planners attempting to design barricade-free preferential lanes for use in mixed traffic. On the one hand, if the preferential lane operates below capacity with a significant speed differential relative to adjacent congested lanes, accidents are almost certain to increase. If the lane is allowed to fill, however, either by allowing violators to infiltrate or by relaxing the requirements for the use of the lane(i.e., by allowing two-person carpools), much of the inducement for using the lane vanishes. In theory, the number of carpools should grow over time until the marginal amount of time saved by switching to a carpool exactly balances the perceived inconvenience of making the switch. In practice, the level of accidents occurring before this equilibrium point is reached may be unacceptable to society, or the equilibrium point itself may result in an unacceptable accident rate.

The specter of increased accidents raises serious questions regarding the feasibility of the barrier-free preferential lane concept. These questions appear to exist whether the lane is created by reserving an existing lane, as was done on the Santa Monica Freeway, or by creating an entirely new lane, as has been done in Portland, Miami, and Marin County, and was originally contemplated for the San Diego Freeway in Los Angeles. The extent of the problem is difficult to assess at present. Although accidents have risen markedly in Marin, neither Portland nor Miami has experienced significant accident increases to date. In both Portland and Miami, however, enforcement activities are reduced, the influx of violators is relatively heavy, and the speed differential is not so great as in the Santa Monica project. Conceivably, the addition of a new preferential lane to an existing freeway could also result in increased accidents if conditions similar to those on the Santa Monica freeway exist. Further investigations of the relationship between accident levels and the operation of barrier-free preferential lanes should be undertaken as soon as possible so that the risks attending these operations may be more clearly defined.

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5. Memorandum from C.P. Sweet to C.E. Forbes, Caltrans. January 11, 1977.