Characteristics of Crashes in Which a Vehicle Overturns

J. W. HALL

The objective of this study is to identify the characteristics of overturning crashes that might be susceptible to correction or amelioration through the application of highway and traffic engineering principles. The study first analyzed information contained in the Fatal Accident Reporting System and then analyzed data from New Mexico, which has one of the nation's highest rates of fatal overturning crashes. National statistics report that overturning is involved in 4 percent of all crashes but in 10 percent of fatal crashes. This study found that, in 11 states, more than 20 percent of the fatal crashes involved overturning. By use of appropriate statistical techniques, the study determined that, in comparison with other crash classifications, overturning occurs with significantly higher frequency under adverse geometric, weather, and lighting conditions. Overturning crashes are also more likely to involve nonlocal drivers and vehicles other than passenger cars. The analysis showed that these crashes had significantly different characteristics than those associated with fixed objects. Therefore, many remedial actions undertaken to reduce fixed-object crashes will have minimal impact on overturning. It is hypothesized that better application of delineation and warning devices could have a positive effect on overturning crash experience in addition to improvements in roadway geometrics. Some roadside design standards may need modification to accommodate the special requirements of certain vehicles. A field study of overturning crash sites is being conducted to obtain more detailed roadway and environmental information on these locations.

Although countless studies of crash occurrence are reported in the technical literature, virtually no attention has been given to the highway-related aspects of the set of crashes grouped into the category of noncollision. This group includes the extremely rare events that involve single-vehicle fires and explosions; however, its principal component consists of crashes in which a vehicle overturns. The crashes predominantly involve a single vehicle and, in fact, according to most schemes for categorizing crashes, a multivehicle crash coded as overturning is probably misclassified. National statistics indicate that only 4 percent of all crashes are classified as overturning, although they are cited in a disproportionate share (10 percent) of fatal crashes. Some western states report that more than 30 percent of their fatal crashes involve overturning.

Despite their substantial contribution to highway fatalities, overturning crashes have not been studied extensively. A recent bibliography of rollover accidents (1) lists several multidisciplinary accident investigation studies of specific overturning crashes but identifies only one study (2) that deals with the highway-related features at single-vehicle crash sites, and the emphasis in this study was fixed objects rather than overturning. A recent Federal Highway Administration (FHWA) study (3) of run-off-the-road crashes addresses some of the problems associated with overturning crashes.

Some researchers have suggested that overturning and fixed-object crashes have generally similar characteristics. The implied assumption is that the roadway, driver, vehicle, and environmental characteristics associated with a vehicle running off the roadway are the same in either case and that the difference is simply whether the roadside at the run-off-the-road location happens to have fixed objects. The logical extension of this assumption is that road-related improvements to reduce fixed-object crashes will also have a favorable effect on overturning crashes. The intent of this study is to examine the characteristics of overturning crashes and to compare them with other types of traffic accidents to establish the validity of this assumption.

The data bases used in the following analyses were obtained from computerized record systems. The classification of overturning was that assigned by the investigating officer. In some instances, such as a vehicle that strikes an embankment and overturns, the officer must make a judgment as to whether the crash should be categorized as fixed object or overturning. The officer's classification, modified to exclude multivehicle overturning crashes, was accepted. It is assumed that classification is reasonably consistent from year to year and among the states.

FATAL ACCIDENT REPORTING SYSTEM

The 1975 Fatal Accident Reporting System (FARS) was used to examine national characteristics related to overturning crashes. The system provides two methods of identifying fatal overturning crashes. A selection based on those crashes where the principal impact point was the top of the vehicle identified 1734 crashes, 18 percent of which were multivehicle. An alternative identification technique, based on those crashes for which the first harmful event is classified as overturning, identified 3038 crashes, only 14 percent of which had a principal impact point on the top of the vehicle. Despite previously noted deficiencies regarding crash classification, the latter group was judged to be more suitable for an analysis of single-vehicle fatal crashes that involve overturning. This set of crashes forms the basis for statistics cited in the following discussion.

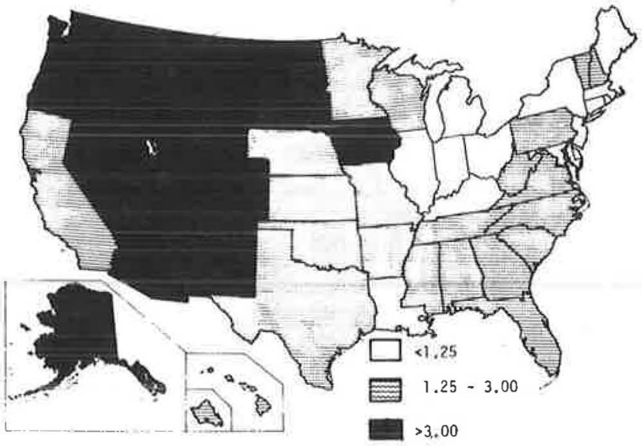
One of the factors that was immediately apparent from an examination of the crash data was the substantial variation in experience with overturning crashes among the states. In most of the primarily smaller, eastern states, overturning crashes constituted less than 6 percent of the annual fatal-accident experience. On the other hand, many western states reported that more than 20 percent of their fatal crashes involved overturning. When experience with fatal overturning crashes is adjusted for travel, a similar pattern is apparent. Figure 1 presents the rate of fatal overturning crashes per billion vehicle kilometers. All of the states that had fatal overturning-crash rates in excess of 3.0/billion vehicle-km of travel report that at least 18 percent of their fatalities are attributable to this manner of collision. Four states (Montana, Nevada, New Mexico, and Wyoming) report that more than one-third of their fatal crashes involved overturning. Although the state rates for fatal overturning crashes are highly correlated with reported fatal accident rates for these states, the unusually high percentages in this category, coupled with the fact that 89 percent of these crashes occur in rural areas, suggest that the western states warrant more attention in this regard.

FARS provides some information on the basic characteristics of these crashes. Reports on almost half the crashes (48.5 percent) for which a roadway alignment was specified indicate that the crash occurred on a curve. In 63 percent of the overturning crashes, the roadway was level. The curvature statistic is in general agreement with the statistics for 7600 run-off-the-road crashes on rural non-Interstate highways (3), although the latter study reports that only one-third of the crashes occur on level roadways. The substantial difference is most likely due to a difference in definitions.

FARS information on light condition indicates that 39 percent of the fatal overturning crashes occur during the day; 53 percent occur during darkness on an unlighted roadway. The portion of fatal overturning crashes during darkness is higher than that for the other fatal crashes.

The statistics also show an unusually high involvement level for pickups and vans. These vehicles are involved in 15 percent of all fatal crashes, and other statistics (4) indicate that this figure is comparable to their proportional share of vehicle registrations in the United States. On the other hand, they were involved in 27 percent of fatal overturning crashes.

Figure 1. Rates of fatal overturning crashes per billion vehicle kilometers.



ANALYSIS OF NEW MEXICO ACCIDENT DATA

FARS analysis confirms the importance, at least for some areas of the country, of overturning crashes in relation to highway safety. In an attempt to further examine the highway and environmental aspects of overturning crashes, an analysis was made of these crashes in New Mexico.

New Mexico has 113 000 km of highway, and annual highway travel is approximately 18 billion vehicle-km. In the past four years, New Mexico has averaged 50 000 accidents/year, and fatalities have averaged 610/year. Although New Mexico's highway fatality rate has decreased in recent years, New Mexico is among the group of states that has the highest fatality and fatal-accident rates. Of relevance to this study is that New Mexico classifies approximately one-third of its fatal crashes as overturning. The 1976 FARS data show that New Mexico has a fatal overturning crash rate of 9.6/billion vehicle-km--the second highest rate in the nation.

The data base used to examine the characteristics of New Mexico's overturning crashes was the 1978 New Mexico accident record system. This system provides information on 55 738 reported accidents, including 580 fatal accidents. The system includes information on urban accidents, including those from Bernalillo County, which accounts for approximately 35 percent of the state's total.

Preliminary analyses of the data were performed by using contingency tables. The comparisons made include the following:

1. A tables--accident classification (i.e., overturn, pedestrian-bicycle, two-vehicle, fixed-object, and other) versus 28 different types of crash characteristics (e.g., severity and lighting);
2. B tables--accident classification as either overturning or other (but excluding pedestrian, bicycle, and single-vehicle motorcycle accidents) versus crash characteristics; and
3. C tables--overturning accident classification only (categorized as either fatal or nonfatal) versus crash characteristics.

The A tables showed the extent to which the characteristics of overturning crashes differed from those that involve fixed objects and the several other crash classifications. The B tables highlighted those areas where overturning crashes differed from the set of other nonpedestrian accidents. Since the contingency table only tests for the independence of the variables, it is appropriate to collapse the table to identify the features that contribute to dependence of the variables. The C tables permitted an analysis of overturning crashes based on their severity. All of the statistical testing performed in this research and reported in this paper used an $\alpha = 0.01$.

A comparison of crash classification versus severity clearly shows the seriousness of the overturning crashes. In 1978, 4213 (fewer than 8 percent) of the crashes involved overturning, but they accounted for 171 (30 percent) of the fatal crashes. In general accord with national statistics, two-vehicle crashes account for 63 percent of the total but for only 34 percent of the fatal crashes. However, the severity statistics are unusual for fixed-object crashes. This crash classification could be viewed as an alternative to overturning in that a vehicle that inadvertently departs from the roadway has the potential for either collision with a fixed object or overturning. National statistics indicate that approximately 13 percent of all crashes involve fixed objects, but they account for 22 percent of all fatal crashes. Statistics from New Mexico indicate, however, that fixed objects are involved in 12 percent of each of the crash severity classifications. A cursory examination of New Mexico roadsides suggests a lower frequency of fixed objects than is found in most other states. To some extent this is reflected by the statistics; for example, only 0.5 percent of New Mexico's crashes involve guardrails. However, the reason for the disparity between national and New Mexico statistics, which exhibit comparable percentages of total fixed-object crashes but a significant difference in fatal crash percentages, is not obvious.

The severity aspects of overturning crashes are even more obvious when the other high-severity classification, pedestrian-bicycle [severity index (SI = 0.93)], is removed. In the tables that follow, pedestrian, bicycle, and single-vehicle motorcycle crashes are excluded. A portion of the B table analysis is presented in the table below to show that the percentage of overturning crashes that result in a fatality or an injury far outweighs their percentage of all crashes. "Other crashes" in the tables that follow include two-vehicle, fixed-object, parked-vehicle, and all other crashes except pedestrian-bicycle and single-vehicle motorcycle accidents.

	Crash Type (%)	
Severity of Crash	Overturning	Other
Fatal	36.8	63.2
Injury	13.1	86.9
Property damage only	5.1	94.9
All	7.4	92.6

The severity of these crashes is also supported by the maximum vehicular damage that results from the crash. More than 67 percent of these crashes result in disabling damage (the most severe code) versus 34 percent for fixed-object crashes and 17 percent for all crashes. One-quarter of the crashes that result in fire are attributed to overturning.

An examination of the roadway alignment characteristic shows that 33 percent of the overturning crashes occur on curves. This percentage is significantly higher than that for all crashes (10 percent) and is significantly higher than that for fixed objects (23 percent). Even when the figures are adjusted to remove pedestrian accidents, the table below shows the unusually high crash experience associated with overturning crashes on curves.

Roadway Alignment	Crash Type (%)	
at Crash Site	Overturning	Other
Straight	5.6	94.4
Curve	23.6	76.4
All	7.4	92.6

However, the percentages are substantially below those obtained from the FARS data. The logical conclusion from this latter comparison, which is supported by an examination of New Mexico's road system, is that a relatively lower percentage of the roadway has curvature.

The New Mexico accident record system classifies roadway grade as level, hillcrest, grade, and dip. By use of this scheme, 85 percent of all accidents reportedly occur on level sections. Since the system does not distinguish between positive and negative grades, the crashes classified in categories other than level were grouped together into an adverse-grade category. Analysis showed that 35 percent of the overturning crashes fell into this category, as opposed to 20 percent for fixed-object crashes and 15 percent for all crashes. These findings are consistent with FARS, but they differ substantially from those reported by FHWA (3), which suggest that only 35 percent of run-off-the-road crashes occur on level roadways. The data presented in the table below show that New Mexico's experience with overturning crashes at adverse-grade locations was significantly higher than would be expected if gradient was independent of crash type.

Roadway Grade	Crash Type (%)	
at Crash Site	Overturning	Other
Level	5.7	94.3
Adverse	17.1	82.9
All	7.4	92.6

A comparison of crash classification versus light condition verifies that a significantly higher than expected number of the overturning crashes occur during other than daylight conditions, although 37 percent occur on dark, unlighted roadways and an additional 10 percent occur on dark, lighted roadways. These figures differ substantially from those for fixed-object crashes, 30 percent of which reportedly occur on dark, lighted roadways. The association of overturning crashes with dark, unlighted roadways, as shown in the table below, is partly a reflection of the rural nature of these crashes.

Lighting Condition	Crash Type (%)	
at Crash Site	Overturning	Other
Day	5.6	94.4
Dawn or dusk	10.9	89.1
Dark, lighted	3.8	96.2
Dark, unlighted	19.9	80.1
All	7.4	92.6

Overturning crashes are found to occur with significantly higher frequencies in New Mexico's less urban counties and with a significantly lower than expected frequency in the principal urban county. Although overturning crashes account for 7.4 percent of the state's total reported accident experience (excluding pedestrians, bicycles, and motorcycles), in one-third of the counties more than 20 percent of the crashes are classified as overturning. On the other hand, fixed-object crashes, which constitute 12.9 percent of the statewide total, represent less than 20 percent of the crashes in each of New Mexico's counties.

The distinction between overturning and other crash types at the county level was examined by using correlation techniques. Both total and fixed-object crashes are found to be highly correlated with county population and population density. On the other hand, the number and rates (based on county population and area) of overturning crashes are poorly correlated with the number or rates of total and fixed-object crashes, population, and area. A linear model to predict overturning crashes based on the number of fixed-object crashes suggests a positive relation but explains only half of the observed variation. This finding detracts from the theory that decreases in the number of fixed-object crashes will lead to an increase in the number of overturning crashes.

An analysis of the weather conditions showed that 88 percent of all crashes occurred during clear weather. The crashes that occur during adverse weather conditions (i.e., rain, snow, fog, dust, and wind) do not show any unusual characteristics, except for those that involve overturning. Actual experience with overturning crashes during rain significantly exceeds what would be expected, and the experience during snow, fog, dust, and wind are each approximately twice the (statistically) expected level. Fixed-object crashes, however, do not exhibit unusual frequency levels for any of the weather categories. Similar findings were obtained from an analysis of road conditions, which showed that a significantly higher percentage of overturning crashes occurred on wet and icy pavement.

The findings of the analyses of weather and road conditions are also supported by the statistics on road defects. Thirty percent of all crashes where a road defect of slippery pavement was reported involved overturning. As shown in the table below, several categories of road defects were much more common at overturning crash sites. Although some lack of consistency may exist in the reporting of road defects, they are cited in only 1 percent of all crashes versus 2.6 percent of fixed-object crashes and 5.3 percent of overturning crashes.

Reported Road Defect	Crash Type (%)	
at Crash Site	Overturning	Other
Slippery	29.5	70.5
Defective shoulder	62.1	37.9
Other	21.4	78.6
All	7.4	92.6

In New Mexico, overturning crashes account for 30 and 2.5 percent, respectively, of the rural and urban crash experience. The record system indicates that approximately 30 percent occur on streets and roadways that are one lane in each direction. However, a substantial number occur on freeways. Not surprisingly, more than 95 percent occur at nonintersection locations.

An analysis of the maximum posted speed at accident sites shows a significant difference between overturning and other crashes. Nearly two-thirds of all overturning crashes, versus 14 percent of other nonpedestrian crashes, occur on roadways where the posted speeds are 80 km/h or greater. The differences shown in the table below are statistically significant and are a reflection of the previously noted high severity.

Maximum Posted Speed	Crash Type (%)	
at Crash Site	Overturning	Other
<55 km/h	1.6	98.4
55-75 km/h	3.3	96.7
>75 km/h	26.5	73.5
All	7.4	92.6

Analysis by day of the week revealed that a significantly higher than expected proportion of overturning crashes (17.3 percent) occurred on Sunday, although the lowest total number of accidents in New Mexico are on Sunday. An even higher (19.6 percent) number occur on Saturday, but the percentage is not significantly different than for other crashes because of Saturday's high accident experience.

With respect to time of day, overturning crashes conform to the patterns reported by others for single-vehicle accidents. They account for more than 15 percent of the crashes that occur between midnight and 7:00 a.m., a figure that is more than twice their proportion of all crashes. However, nearly 30 percent of the crashes during this seven-hour period involve fixed objects--a figure that is even less in line with their 12.9 percent share of all accidents. The lighting analysis showed that fixed-object crashes occur with unusually high frequency on dark, lighted roadways.

To examine the trend suggested by the FARS data that pickup trucks are involved to an unusually high extent in these crashes, an analysis was made of vehicle types. Although passenger cars are involved in two-thirds of all crashes, they constitute only 44 percent of the vehicles in overturning crashes. However, pickup trucks, tractor-trailer combinations, motorcycles, and vans are all significantly overrepresented among overturning vehicles. None of the other crash classifications exhibits a significant variation among vehicle types. The table below, which is based on the crash population excluding pedestrian and motorcycle crashes, shows the unexpectedly high involvement by vehicles other than passenger cars.

Vehicle Involved in Crash	Crash Type (%) Overturning	Other
Passenger car	5.0	95.0
Pickup	11.4	88.6
Van	15.2	84.8
Tractor-trailer	22.9	77.1
Other	8.4	91.6
All	7.4	92.6

Two human-related factors of overturning crashes warrant consideration. The first involves the driver's familiarity with the road and is suggested by the category of local versus nonlocal drivers. More than 71 percent of the drivers involved in overturning crashes were classified as either "nonlocal in-state" (48 percent) or "out-of-state" (23 percent). These figures are significantly different from those for fixed-object crashes, which involved only 34 percent unfamiliar drivers. The remaining crash classifications reported an average of 33 percent unfamiliar drivers. The table below shows the disparity between overturning and other crashes with respect to this characteristic.

Residence of Driver Involved in Crash	Crash Type (%) Overturning	Other
Local	3.1	96.9
Nonlocal, in-state	14.8	85.2
Out-of-state	18.7	81.3
All	7.4	92.6

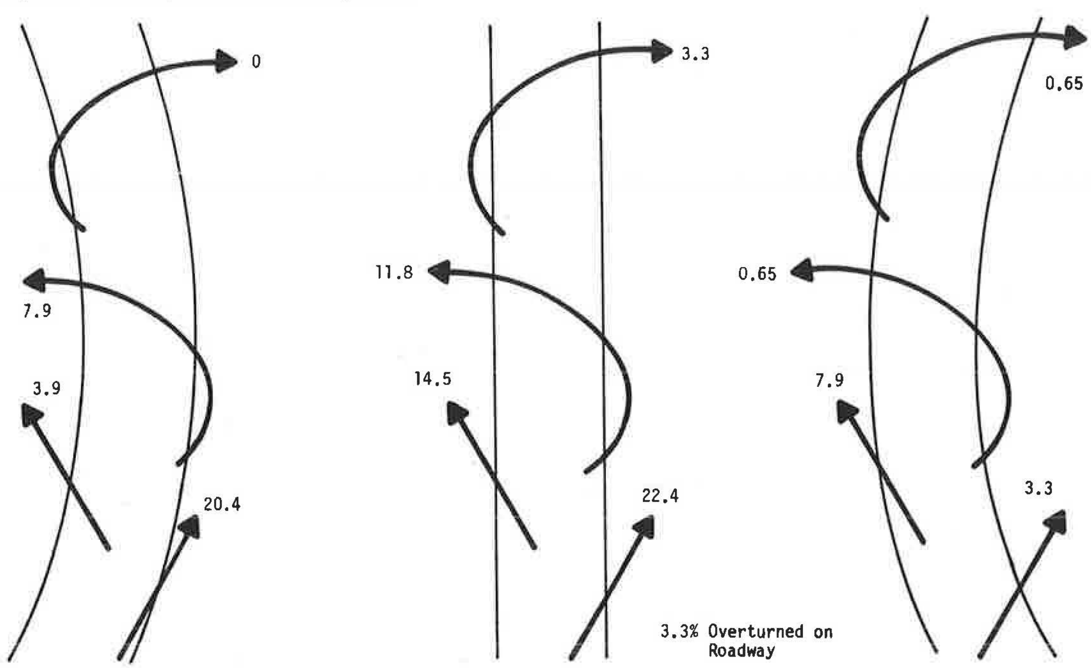
A second characteristic that may be of concern is the principal (reported) factor contributing to the crash. Approximately 16 percent of the overturning crashes reportedly have alcohol involvement (8.9 percent cited for driving while intoxicated) versus 22 percent for fixed-object crashes (15.9 percent driving while intoxicated) and 11 percent for all crashes (7.5 percent driving while intoxicated). Although these figures probably understate the actual involvement of alcohol, it is apparent that alcohol is involved to a considerably lower degree than in fixed-object collisions.

The C tables were used to compare the characteristics of the 171 fatal overturning crashes with the 4042 that resulted in nonfatal injuries or property damage only. In general, few characteristics were significantly different. Alcohol, higher posted speed limits, and dark, unlighted roadways were reported for fatal overturning crashes at moderately higher levels than would be expected. Adverse pavement conditions (primarily snow and the road defect of slippery pavement) were reported at significantly lower levels. A dramatic distinction between the fatal and other overturning crashes is the reported driver use of restraint systems. In fatal crashes, a significantly low number of drivers used seat belts. The analysis found that 63 of the drivers in fatal crashes were ejected, whereas only 4 ejections would have been expected. There were no significant differences with respect to features such as roadway alignment, unfamiliar drivers, and vehicle type, which were earlier found to be different among various crash classifications.

The foregoing analyses pretty much exhaust the information that can be obtained from the computerized accident record system. One factor of importance provided on the accident report form but not contained in the computerized system is the manner in which the vehicle left the roadway. To examine this point, a sample of fatal overturning crash reports was examined. The existence of curvature was determined from the officer's narrative and sketch rather than from the code for road character. It was found that 55 percent occurred on tangents, 32 percent on curves to the left, and 13 percent on curves to the right. Not surprisingly, when the few crashes that involved overturning on the roadway were excluded, half of the vehicles overturned on the right side and half on the left side.

The data showed, however, that 27 percent of the overturnings occurred on the opposite side of the road from which the vehicle initially departed. In virtually all of these cases, the officer stated that the driver left the roadway and overcorrected. Figure 2 shows the percentages of various maneuvers prior to overturning. Statistics that state only the side of the roadway on which the vehicle initially departed or only the side of the roadway on which the vehicle overturned do not reflect the overcorrection factor suggested by the maneuvers in the figure.

Figure 2. Vehicle departures in overturning crashes.



CONCLUSIONS

The analysis of FARS and New Mexico data leads to several conclusions about the nature of overturning crashes. They are seen to be a substantial component of the total accident picture, and their typical classification as apparently minor noncollision accidents seriously understates their importance. In those states where they are responsible for more than 20 percent of the annual highway fatalities, they clearly warrant more attention.

A principal finding of the study is that significant differences exist between the characteristics of overturning crashes and those that involve fixed objects. The specific differences between these two classes are as follows: (a) overturning crashes have higher severity, (b) they are more likely to occur on curves or grades, and (c) they are more closely related to adverse weather conditions. Other characteristics that distinguish overturning crashes from fixed-object crashes are their rural locations (also reflected by the dark, unlighted condition and maximum speed), the higher involvement of unfamiliar drivers, vehicles other than passenger cars, road defects, and the lower rate of alcohol involvement. The significant differences in roadway, environment, vehicle, and driver between these two crash classifications is a strong indication that remedial programs directed toward fixed-object crashes and severity reduction will not necessarily have an effect on overturning crashes.

The analyses suggest several things that are of importance to the transportation engineer. The existence of adverse geometrics at crash sites has been shown to be more common at fixed-object crash sites (2), but it appears to be even more prevalent at overturning crash sites. The excessive involvement by unfamiliar drivers suggests the need for improved positive guidance through the application of better delineation and improved warning. The transportation engineer can do little to control the registration and use of vehicles; however, the significantly higher overturning crash experience associated with certain vehicle types suggests that existing design standards for roadways and roadsides may not adequately address the special characteristics of these vehicles. And finally, the unsuccessful maneuvers that some drivers make, which result in overcorrection, may be susceptible to correction through improved shoulder design and maintenance.

The analyses reported in this paper are based primarily on accident record systems. Many crash-related factors that are of interest to the transportation engineer are not adequately or accurately reflected in the computerized record systems. It is therefore risky to draw far-reaching conclusions simply from an analysis of these systems. To counteract this problem, a program is currently under way in New Mexico to collect detailed information concerning the roadway and roadside characteristics at a sample of the overturning crash sites. Results from this study are anticipated in the spring of 1980.

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Operations and Design Guidelines for Facilities for High-Occupancy Vehicles

DEAN BOWMAN, CRAIG MILLER, AND BOB DEUSER

Design guidelines intended to enhance the safety of high-occupancy vehicle (HOV) preferential-treatment projects are proposed. These guidelines reflect the principal findings of a nationwide research program sponsored by the Federal Highway Administration in 1977 that involved the examination of more than 22 HOV projects for safety issues. Virtually every type of HOV technique was investigated, including freeway and arterial separated facilities, concurrent-flow lanes and contraflow lanes, freeway toll-plaza lanes, freeway ramp treatments, and arterial bus-preemption strategies. Cause-and-effect relationships of accident patterns on these projects were investigated and general guidelines formulated. Based on this analysis, HOV treatment-specific recommendations are offered to assist transportation planners and designers in improving the operations and design of HOV facilities with respect to safety.

In the United States, the 1970s were characterized by a proliferation of high-occupancy vehicle (HOV) preferential-treatment projects. Contraflow HOV lanes on arterials and freeways, concurrent-flow arterial freeway lanes, ramp-metering bypasses, separate freeway transitways, toll-plaza priority lanes, downtown transit malls, and signal preemption have all been recently implemented with their own particular design and operational features. The variance in design and operational features even exists among individual applications of the same type of preferential treatment. Without nationally established guidelines, the local project manager has been left to develop project-specific design standards, traffic control devices, and operating strategies. As a result, an extensive experimental base has been established from which local innovations can be analyzed comparatively for safety and operational implications.

In 1977, the Federal Highway Administration (FHWA) initiated such a study to survey existing HOV projects and examine the relationship between project characteristics and accident patterns (1). The research focused on five major areas associated with HOV projects:

1. Examination of accident rates,
2. Analysis of causative factors that influence safety,