An Analysis of Safety at Upgrade Terminals of Climbing Lanes on Two-Lane Highways

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In this paper, an investigation of traffic flow at the upper end of climbing lanes on two-lane roads in northern and central California is summarized. It was postulated that, especially where such lanes end on an upgrade, there might be sideswipe accidents involving merging vehicles or head-on collisions between a vehicle swerving across the centerline to avoid such a sideswipe and a vehicle traveling in the opposite direction. Accident records covering 5 years at 21 such locations revealed that there are few accidents directly related to the merging maneuver; only 11 such accidents at six locations were identified. At only one of these locations were there a sufficient number (five) of accidents to warrant detailed analysis. The study of this location showed that the relatively short length of the climbing lane may cause impatient drivers to attempt last-chance overtaking maneuvers, and that restricted sight distance beyond the merging area may fail to warn uphill drivers of traffic approaching in the downhill direction. Three guidelines for the location and design of climbing lanes are suggested for consideration in addition to those found in other literature. However, the general conclusion is that the merging areas at the terminals of climbing lanes on two-lane roads do not present a hazard of major proportions.

It has been known for several decades that there is a direct relationship between accidents and speed differences within a traffic stream. One might therefore postulate that potential safety hazards exist at the upper terminals of climbing lanes, especially on upgrade sections to two-lane roads where vehicles traveling at substantially different speeds must merge. In theory, climbing lanes are used by slow-moving vehicles, while the faster traffic remains in the through lane. In practice, a substantial proportion of faster traffic may also use the right-hand climbing lane in the absence of slower vehicles to be overtaken. It appears reasonable to expect that faster vehicles might make unsafe merging or overtaking maneuvers in such areas because of the prospect of being detained behind slow vehicles on the next section of the road.

This study was therefore undertaken with three objectives in mind:

- To determine the extent of the safety hazards at merging areas on upgrades where climbing lanes terminate, primarily by analysis of accidents reported at such locations.
- To relate accident patterns to horizontal and vertical alignment characteristics in the vicinity of the merging area and to traffic composition.
- To suggest modifications in design of traffic controls that might enhance safety in the vicinity of merging areas at the upper terminals of climbing lanes.

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As will be shown, the basic hypothesis appears to have been of doubtful validity. In the records studied, only a few accidents can be attributed directly to or related indirectly to the merging maneuver. A 3-hr film record of traffic on what was found to be the only climbing lane in northern and central California with a pattern of merging accidents (five in 5 years) shows some signs of perceived potential hazards in the form of brake applications and some possibly hazardous encroachment of the centerline of the highway. Skidmark evidence found at some other sites indicated that near misses appeared to occur, and some may have been laid down in the course of minor accidents that were not reported.

LITERATURE REVIEW

A brief review of the literature on climbing and passing lanes and on methods of analyzing traffic flow and safety on such lanes revealed three studies that are particularly useful to the analysis of this problem.

Botha's Simulation Model *(1, 2)*

A microscopic stochastic model for simulating climbing lanes on two-lane rural roads was developed at the Institute of Transportation Studies, University of California at Berkeley. The model was later modified to account for potentially hazardous maneuvers and to combine them into a single potential hazard index.

During the development of the model, time-lapse photography studies were conducted at two sites using five cameras. Cameras were located at the merging terminal of the extra lane and downstream. For the refinement of the model, an additional time-lapse photography study was conducted of only the merging area at another location. Some results pertinent to this paper *(2)*, are summarized here:

- The majority of drivers (85.5 percent of 351 vehicles observed in one sample) merged within 100 ft of the end of the climbing lane taper. The calculated travel time to the end of the lane from the point of merge was less than 2 sec for 97. 5 percent of the cars.
- The average gap length accepted by vehicles merging in the climbing lane terminal zone was 507.8 ft. Most of the accepted gaps, 87.3 percent, were more than 500 ft long and only 1.5 percent were less than 100 ft.
- Many vehicles strayed beyond the edgeline or centerline

of the merge area. Of 2,570 uphill vehicles observed in another sample, 2.4 percent encroached on the shoulder and 1.7 percent crossed the centerline marking. These encroachment rates are quite high when compared with those obtained by Harwood and St. John *(3)*.

The Midwest Research Institute Study

Harwood and St. John *(3)* conducted research on the safety of two-lane highways to determine the traffic and safety effects of selected treatments designed to reduce operational problems on this type of facility. Passing lanes that were not necessarily uphill were one of the treatments considered. The study was conducted with the participation of 13 state highway agencies.

This report has an excellent summary on current practice in design and traffic control for passing lanes. The field work included collection of traffic flow and accident data at 66 sites and studies of vehicle conflicts (when a vehicle is required to take evasive action to avoid a collision) and of erratic maneuvers (unusual driving action by a single vehicle) in the area of lane drops of 10 of these sites. The following is a summary of the results:

Passing Lanes Generally

- Sites with passing lanes had 38 percent fewer accidents than comparable sites without them.
- The mean rate of accidents in the treated direction at passing lane locations was slightly higher than in the non-treated direction. The difference was not found to be statistically significant.
- By using before and after studies, the available data strongly suggested that the installation of passing lanes may decrease accident rates. However, the differences were not statistically significant, perhaps because of the short study period used.

Lane Addition and Lane Drop Areas

- There is no indication of any marked safety problem in the lane addition and lane drop transition areas.
- In the traffic conflict study at lane drop areas, most commonly observed was the slow-moving vehicle conflict, with a rate of 0.8 per 100 vehicles braking or swerving to avoid a slower vehicle in front of them. Next were lane changes that caused other vehicles to take evasive action with a rate of 0.29 percent, and slow-to-merge conflicts with a rate of 0.19 percent. Together they represent 98 percent of the total conflict rate of 1.3 per 100 vehicles.
- The erratic maneuver study found centerline and shoulder encroachment rates to be 0.48 and 0.31 per 100 vehicles, respectively. As mentioned, these are lower than those found by Botha *(2)*.

Australian Road Research Board

Hoban and Morrall *(4)* compared work done by Morrall at the University of Calgary with Australian practice concerning the use of overtaking lanes on two-lane rural highways. The survey included responses from the California Department of Transportation (Caltrans), the Colorado Department of Highways, and the Department of Transport of the United Kingdom, as well as Canadian and Australian sources. The previous studies *(2, 3)* were included; hence the conclusions reached in this work also reflected the items summarized in the preceding sections.

This report offers nothing additional on the subject of safety, relying almost entirely on the Midwest Research Institute study *(3)* when discussing this topic. However, it is of interest because of the material dealing with the lengths of passing lanes that will be discussed in the section on Meyers Grade climbing lane. While some information appears contradictory, it is worth summarizing (Note: 1,000 m = 3,280 ft).

- The Ontario Ministry of Transportation and Communications (OMTC) "has found that overtaking lanes between 1,500 and 2,000 m in length cover most situations" *(4*, p. 31). However, a chart developed by OMTC shows recommended minimum and maximum lengths for such lanes of 1,000 and 1,250 m, respectively.
- The Province of British Columbia uses 800 m as the minimum length and 1,000 m as the minimum desirable length of truck climbing lanes.
- Australia has developed minimum, recommended, and maximum lengths for auxiliary lanes based on research by Hoban *(5)*. These lengths depend on the design speed of the highway, as shown in Table 1. They are based on the observation that most passing activity occurs near the beginning of the auxiliary lane and relatively little later on.

TABLE 1 AUXILIARY LANE LENGTHS *(4*, p. 36)

Design Speed[a] (km/hr)	Total Tapers (m)	Auxiliary Lane Lengths, Including Taper (m)		
		Minimum	Recommended	Normal Maximum
50	125	200	350	450
60	150	250	400	550
70	175	300	500	650
80	200	400	600	850
90	225	500	700	1,000
100	250	600	800	1,200

[a]For the section on which the auxiliary lane is constructed.

This report therefore shows that minimum length standards for passing lanes vary rather widely among the jurisdictions surveyed. Even the basic concepts differ, with design speeds being considered as a major factor in Australia, but not in Canada. Australian values are generally lower than Canadian ones, except where design speeds are high.

INVENTORY OF CLIMBING LANES AND SAMPLE SELECTION

A preliminary inventory of uphill climbing lanes on two-lane highways in northern and central California was developed based on the *California State Highway Log (6)*. Discussions with Caltrans staff in several district offices indicated that most locations of interest were in northern and central California. A total of 104 climbing lanes were selected as a sample; criteria for inclusion were a merging area on an upgrade, substantial annual average daily traffic (AADT), and appreciable proportions of trucks and recreational vehicles (RVs).

The first screening process eliminated those sites with AADT less than 2,000 and grades less than 2 percent. The remaining 89 sites were reviewed using the photolog for California state highways. This photolog comprises photographs taken through the windshield of a vehicle at intervals of 0.01 mi, from which a visual impression of any site on the state highway system can be obtained. Descriptions of vertical and horizontal alignments, of sight distances, and of passing ahead conditions were recorded. The latter were described using qualitative ratings of excellent, good, average, restricted, and very restricted. The first, third, and fifth of these are defined in the following table; the others are intermediate conditions.

Rating	*Sight Distance*	*Passing Ahead*
Excellent	Sight distance exceeds stopping sight distance	Unrestricted passing opportunities ahead
Average	Close to minimum stopping sight distance	Safe passing available only in short segments
Very restricted	Equal to or less than minimum stopping sight distance	Safe passing almost impossible or not permitted

The inventory also contains the location of the beginning and end of the climbing lane to the nearest 0.01 mi, the direction of the lane, the AADT, and the percentage of trucks. Grade was obtained by inspection of as-built drawings or by correspondence with highway engineers in Caltrans field offices.

Accident experience at each location was obtained from the Traffic Accident Surveillance and Analysis System (TASAS) for segments from 0.25 mi before to 0.25 mi after the end of the climbing lane, defined as the point where the taper disappears, for the period 1980–1984. Those accidents occurring within 0.10 mi of the end of the climbing lane were also used as a separate data group. Milepost data in TASAS reports are not always exact; however, while this inaccuracy may slightly affect the preceding accident rates, it is not believed to have affected other results.

A sample of 21 locations was chosen for detailed study. Selection criteria included sites with restricted geometry (based on the photolog) and with high accident rates (based on TASAS), and sites considered by Caltrans as likely problem locations (based on their experience). This sample includes all but one of the locations at which the accident rate within 0.25 mi of the merging point exceeded 400 per 10^8 vehicle-miles per year.

ACCIDENT ANALYSIS

Next, exact causes of the individual accidents in merging areas of climbing lanes were analyzed and related to the grade and alignment characteristics of the merging areas and to traffic flow.

The first step consisted of gathering the individual accident reports for all 21 sites (within 0.1 mi) and the as-built plans. The latter, however, were not complete and were often too old, dating back to the 1930s and 1940s. Thus, field inspection and measurement were required at the sites of greatest interest to confirm the existing geometric characteristics. At the same time, other sites along one major two-lane road (State Route 50) at which no accidents had been reported, were inspected. At most locations, skidmarks were noted, indicating that potentially hazardous conditions caused some drivers to lock their wheels in attempts to decelerate rapidly. However, in no case were there so many skidmarks as to indicate a frequently recurring problem.

Of the 157 reported accidents occurring within 0.1 mi of the end of the merge taper during the 5-year period, only 11 seem to have been related to the merging maneuver. Of the rest, 78 were single-vehicle accidents, 55 others occurred when either one vehicle or none were moving uphill, and 13 were primarily attributable to snow and ice conditions, alcohol, or other non-merging causes.

A preliminary judgment must be that there is no major safety problem in the merging areas of these climbing lanes and, if the sample did indeed include all the locations most likely to present hazards, in such areas generally. With such a small number of accidents, statistical testing becomes impossible. Therefore, the 11 reports were used to detect any common factors or circumstances.

The 11 merging-related accidents occurred at six sites on three highways. Table 2 summarizes relevant information of these sites. It is noted that five locations are at points where safe passing downstream of the merge is almost or completely impossible, that is, classified as restricted or very restricted in the passing ahead column in the table. Several of the accidents recorded appear to have been caused by drivers making a last-chance attempt to overtake a slow vehicle, presumably aware that the next passing opportunity would lie far ahead.

A summary of information about each of the 11 accidents follows. These data come from the original accident reports of the California Highway Patrol Form 555, as filled out by the investigating officer. Unless otherwise noted, accidents occurred in daylight and good weather conditions. The last column of Table 2 indicates at which site each accident took place. To clarify the descriptions, vehicles and drivers involved in the more complicated accidents are assigned letters.

1. *Description of events:* An uphill motorcycle passed a slow-moving vehicle on the right. In attempting to cut back at the merging area, the cycle hit an oily spot on the pavement, lost control, and slid sideways. There was no collision with the other vehicle.

Severity: The motorcycle operator and passenger were injured.

2. *Description of events:* A motorhome was moving uphill in the merging area. The driver of automobile *A* attempted to pass it, then braked suddenly upon the realization that the passing maneuver could not be completed, and swerved to the left. Motorcycle *B*, close behind *A*, struck it in the rear, went down, and slid into the downhill lane. Another downhill vehicle *D* ran over the motorcycle.

Severity: One motorcycle rider was killed, the other injured.

3. *Description of events:* The driver of an uphill vehicle started to pass another vehicle (type unidentified), then changed her mind and braked. The brakes were apparently wet,

TABLE 2 SITES WITH MERGING-RELATED ACCIDENTS

Site No.	Climbing Lane Length and AADT	Vertical Alignment	Horizontal Alignment	Sight Distance	Passing Ahead	Accidents[a] Total and Rate	Accidents[a] Merging-Related
1	0.13 mi 3,400	Up 8.5%. No crest	Tight curve	Restricted	Very Restricted	20 1,612[b].3m' #1[c]	1
2	0.73 mi 9,725	Up 6.0%. No crest	No curves	Excellent	Restricted	10 282[b].3m' #2[c]	1
3	0.81 mi 9,725	Up 5.0%. Crest	After a curve	Good	Average	12 364[b].3m' #3[c]	1
4	0.16 mi 11,000	Up 5.9%. No crest	Slight curve	Good	Restricted	17 466[b].3m' #4-8[c]	5
5	0.22 mi 2,200	Up >5%. No crest	In middle of tight curve	Restricted	Restricted	6 747[b].3m' #9[c]	1
6	0.28 mi 2,200	Up >5%. No crest	In curve	Restricted	Very Restricted	4 498[b].3m' #10-11[c]	2

a - Accidents within ±0.10 mile of end of merging taper, 1980-84.

b - Accidents per 10^8 vehicle-miles.

c - Numbers refer to accidents described in text.

Source: California Department of Transportation photolog, site plans, correspondence, TASAS, and (*6*).

as a result of which the car crossed the road centerline and collided with a downhill vehicle.

Severity: Property damage only (PDO).

Special condition: Wet pavement.

4. *Description of events:* As a platoon of uphill cars was passing through the merging area behind an intercity bus, a pickup truck *A* started to pass the bus. A downhill automobile *B* swerved toward the snow bank on the right shoulder, was sideswiped by *A*, then lost control and crossed the highway, colliding with another uphill vehicle *C*. *A* left the scene without stopping (hit-and-run).

Severity: There were four injury victims.

Special condition: Pavement dry, but snow banks along edge of shoulders.

5. *Description of events:* An uphill vehicle *A* was passing traffic at high speed (50 to 60 mph) and continued to pass after the "Do Not Pass" sign. The driver hit the brakes to try to merge, but slid into the downhill lane, colliding with downhill vehicle *B*.

Severity: Driver *B* was injured.

6. *Description of events:* An uphill car attempted to pass a bus in the merging area without sufficient clearance, and sideswiped the left front of the bus. The car failed to stop (hit-and-run).

Severity: PDO.

Special condition: Darkness.

7. *Description of events:* An uphill motorcylist *A* in passing two vehicles at 60 to 70 mph ran out of room in the merging area, crossed the centerline, and collided with a downhill vehicle *B* that appeared suddenly around the curve. Another downhill vehicle *C* skidded in attempting to avoid the accident area and crossed into the uphill lane, colliding with another uphill motorcycle *D* which failed in its attempt to take evasive action.

Severity: Driver *A*, five occupants of vehicle *B*, and both riders on vehicle *D* were injured.

Special note: Driver *A* had been drinking—impairment unknown; driver *D* had been drinking—not under the influence.

8. *Description of events:* An uphill pickup truck *A* pulling a trailer was overtaking a cement truck (*B*, possibly a concrete mixer) in the merging area, when a downhill vehicle appeared around the curve. As a result, *A* merged to the right abruptly, causing a minor sideswipe collision with *B*.

Severity: PDO. Both vehicles were able to continue to the summit before stopping to make a report.

9. *Description of events:* An uphill automobile failed to complete the passing of a truck before the end of the merging lane. As the truck moved toward the left, the two vehicles sideswiped.

Severity: PDO.

10. *Description of events:* A pickup hauling a trailer *A* uphill was overtaken by an automobile *B* in the merging area. Where the lane narrowed, *B* sideswiped the left front fender of *A*. *B* did not stop (hit-and-run).

Severity: PDO.

11. *Description of events.* A truck-trailer combination *A* attempted to overtake an asphalt truck moving uphill at 15 mph. The passing lane has sharp curves, first to the right and then to the left. In order to avoid the trailer crossing over the centerline at the second curve, the driver steered the tractor partly into the climbing lane. A following pickup truck *B* thought that *A* was changing lanes and started to overtake. When *A*'s tractor steered back into the through lane, *B* collided with the trailer. While these events do not relate directly to the upper end of the climbing lane, the proximity of that point may have caused both drivers to press forward anxiously to complete their respective overtaking maneuvers.

Severity: PDO.

Summary of Accident Types

Ten of the 11 accidents fell into two groups of five each:

1. Sideswipes of vehicles traveling in the same direction being squeezed when attempting to merge (Accidents 6 and 8–11). All were PDO.
2. Head-on collisions, sometimes preceded or followed by other collisions, caused when a driver attempting to overtake in the merging area crossed the centerline (Accidents 2–5 and 7). All but one of these resulted in more serious consequences, including injury and death.
3. Accident 1 was a single-vehicle noncollision accident resulting in two injuries.

THE MEYERS GRADE-CLIMBING LANE

Site 4 (Table 2) was selected for detailed analysis because it was the only location found where more than two merging-related accidents in the 5-year period for which traffic accident data were analyzed occurred. The purpose of the field work was to obtain data that would permit calculation of the benefits provided by the climbing lane; this might then be compared with the safety record of the location.

Westbound State Route 50 approximately between mileposts 70.0 and 66.5 ascends at a 6 percent grade. Site 4, the only climbing lane on this grade, is located between mileposts 67.90 and 67.74. It is therefore encountered after over 2 mi of uphill driving, and is only about 800 ft long. Motorist frustration may be assumed to be a factor when faced with such a short passing opportunity after a fairly long constrained climb.

The lane is mostly on a curve toward the left for uphill traffic, but ends on a tangent section. Immediately beyond the merging area, the highway curves toward the right with restricted sight distance due to a high bank next to the inside shoulder. Complicating the situation somewhat, but evidently not contributing to the safety record of the location, is the intersection on the right side facing uphill near the merging area with the old Echo Pass road; this road carries very low traffic volumes in the summer and is closed in the winter.

In August 1985, traffic in the merging area was filmed for about 3 hr. During this period, uphill traffic was about 400 veh/hr; 1,185 vehicles are in the film data, representing 15 percent of the peak-month, one-directional ADT of 7,850 vehicles *(7)*; a two-directional ADT of 15,700 for the peak month, which is probably August, is shown. Table 3 summarizes the principal data obtained in this study.

Only the upper third of the climbing lane appears in the film, but the amount of passing that took place in the lower two-thirds can be conjectured from the relative positions of slow-moving vehicles in the platoons as they appeared in the camera range. A length of 200 ft corresponding roughly to the merging area was identified for speed and gap measurement purposes.

A group of vehicles was defined as one or more vehicles separated from the last preceding vehicle and from the next following vehicle by amounts of time, during which the 200-ft merging segment was unoccupied, of

- ≥6.5 sec if the first vehicle in the camera range after such an interval was a slow-moving one (i.e., trucks, bus, RV, or other vehicle hauling a heavy trailer). There were few such cases.
- ≥2.5 sec if the first vehicle after such an interval was a fast vehicle, any vehicle not defined as slowly moving.

Even a single vehicle meeting these separation criteria is referred to as a group; groups of two or more vehicles constitute platoons.

Because the time required to travel the 200-ft segment averages 5.5 sec for slow-moving and 3.5 sec for fast vehicles, these minimum separations correspond to gaps, as this term is used in the traffic flow literature, of about 12 and 6 sec, respectively. These gaps are greater than those reported by Harwood and St. John (*4*, p. 23) to have been used in other research, but seem appropriate for the slow speeds at this site: they correspond to spacings in the range 375 to 450 ft. The noninteger values arise from the fact that they are halfway points between integer seconds recorded from the film.

This definition allows for the probability that some fast vehicles will have overtaken platoon leaders in the portion of the climbing lane that was upstream out of the camera range.

The uphill traffic flow recorded on film was analyzed with respect to the following phenomena:

- The length of time when no vehicle occupied the 200-ft section of roadway defined as the merging area.
- The number of vehicles per group.
- The number of slow-moving vehicles in each group.
- The number of vehicles that preceded the slowest vehicle in each platoon; these were assumed to have overtaken the original platoon leader.
- The length of gaps between groups.
- The lane distribution.
- The number of vehicles displaying brake lights in the merging area. Under normal uphill conditions, one vehicle can slow down to yield to another in the merging area just by coasting; the application of brakes might therefore be considered as a reaction by a driver to what is perceived as a potentially hazardous situation.
- The number of vehicles in the center lane that encroached on the downhill lane by crossing the double-yellow centerline marking.
- For each group, whether downhill traffic appeared, creating a potential for collisions with uphill traffic straying across the centerline.

The following conclusions or insights may be drawn from these data:

TABLE 3 SUMMARY OF DATA FROM TRAFFIC OBSERVATIONS ON STATE ROUTE 50 AT MEYERS GRADE

Data Item	Single Vehicles		Vehicles in Platoons		Total	
	No.	%	No.	%[a]	No.	%[a]
Total vehicles observed	98	100.0	1,087	100.0	1,185	100.0
Passenger cars	94	95.9	992	91.3	1,086	91.6
Trucks	2	2.0	26	2.4	28	2.4
RVs and other slow vehicles	2	2.0	60	5.5	62	5.2
Motorcycles	0	0.0	9	0.8	9	0.8
Number of vehicle groups[b]	98	100.0	232	(100.0)	330	[100.0]
Platoons where some over-taking took place	NA	NA	44	(19.0)	NA	NA
Platoons where no over-taking took place	NA	NA	188	(81.0)	NA	NA
Number of vehicles:						
Overtaking others	NA	NA	144	13.2	144	12.2
Not overtaking others	98	100.0	943	86.8	1,041	87.8
Of these--other than platoon leaders	NA	NA	711	65.4	711	60.0
Of these--cars in platoons led by a slow vehicle	NA	NA	222	20.4	222	18.7
Lane distribution						
Vehicles in climbing lane	88	89.8	644	59.2	733	61.8
Vehicles in through lane	10	10.2	443	40.8	453	38.2
Brake application						
Groups[b] in which at least one vehicle braked	6	6.1	79	(34.1)	85	[25.8]
Vehicles applying brakes	6	6.1	162	14.9	168	14.2
Centerline encroachment						
Groups[b] in which at least one vehicle encroached	2	2.0	51	(22.0)	53	[16.1]
Vehicles encroaching	2	2.0	62	5.7	64	5.4
Vehicles encroaching with downhill traffic present	0	0.0	25	2.3	25	2.1

a - Numbers in ( ) are percent of platoons, those in [ ] percent of groups, all others percent of vehicles.
b - See text for definition of "group".
NA - Not applicable.

- The proportion of platooning (groups of two or more vehicles) was large; 91.7 percent of all vehicles were moving in platoons. This proportion cannot, however, be compared directly with corresponding numbers in the work of Harwood and St. John *(3)* because of the differences in the definition of platoons.
- The average platoon size was 4.7 vehicles. The distribution of group sizes and the percent of all vehicles in groups of various sizes are shown in Figure 1.
- In only 19 percent of all platoons did at least one vehicle overtake the leading vehicle; only 13.2 percent of vehicles in platoons (12.2 percent of all vehicles) overtook one or more other vehicles.
- About 60 percent of vehicles in platoons used the climbing lane, 40 percent the left (through) lane. By comparison, 90 percent of single vehicles traveled in the climbing lane and only 10 percent in the through lane. For 27 percent of all platoons, the left lane was not used at all. (No attempt was made to overtake.)
- About 15 percent of vehicles in platoons applied brakes in the merging area; such an event occurred in 34 percent of all platoons. Six single vehicles also used their brakes.
- The centerline was crossed by 5.7 percent of vehicles in platoons involving 22 percent of all platoons and two single cars that were not faced with any merging problems. This proportion is considerably higher than those reported previously *(2, 3)*.
- About 60 percent of all platoons met oncoming traffic in the merging area, and 37 percent met a vehicle in the curve beyond the merge.

Calculations of Time Saved by Climbing Lane

When the speed data derived from the film are used, the camera speed of 1 frame per second produces imprecise travel time measurements and resulting speed calculations. The accuracy for fast vehicles is about ±17 percent, for slow vehicles about ±8 percent. But, while individual errors may be of these magni-

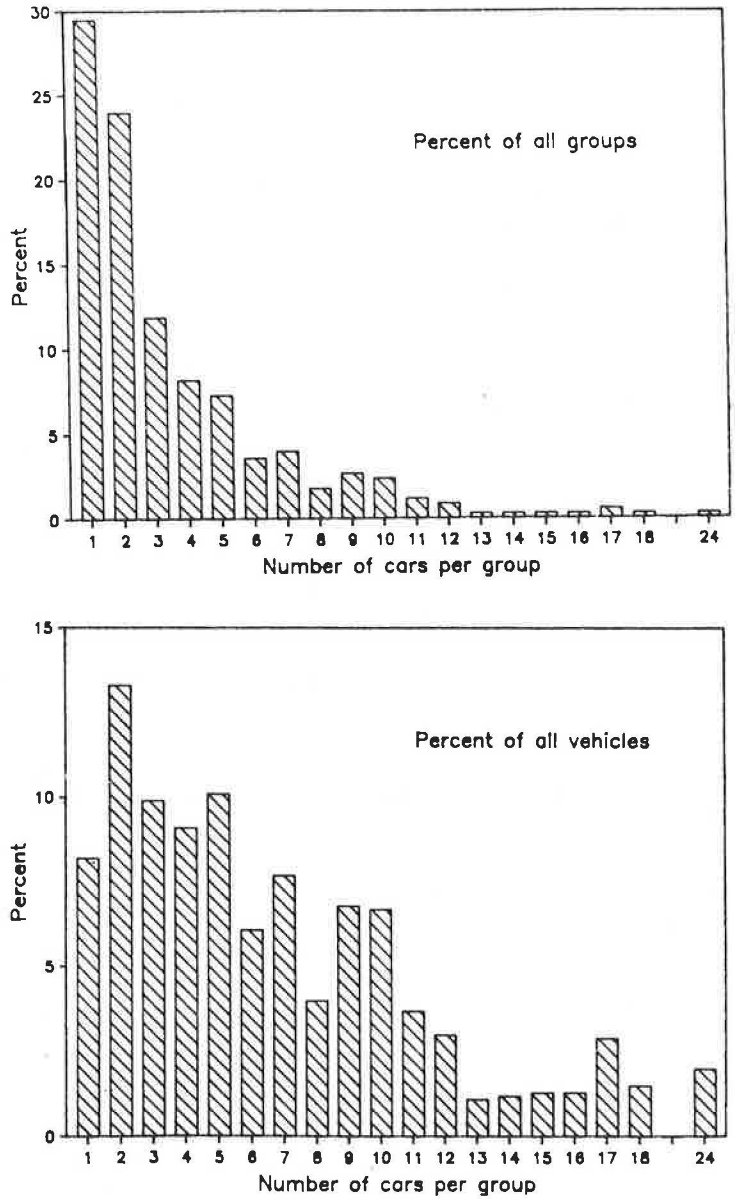

FIGURE 1 Distribution of group sizes, Meyers grade study.

tudes, they tend to cancel each other, and values for mean speeds should be somewhat more accurate.

The data obtained over the period sampled for a total of 1,185 observed vehicles were expanded to an AADT of 5,500 vehicles *(7)*, this is one-half of the AADT of 11,000 for both directions reported for this location. The AADT is used instead of the ADT because time and cost savings are calculated on an annual basis.

The calculation assumes that the existence of the climbing lane enabled some passenger cars, by overtaking slow-moving vehicles, to continue to Echo Summit at the speed of single, unconstrained cars. This probably overstates time savings because of the likelihood of cars catching up with other slow vehicles before reaching the summit. It was not deemed cost-effective in this research to use computer simulation to represent the uphill lane between the camera location and the summit in view of the unlikely increase in accuracy of the result by such a method. The distance from the middle of the climbing lane, where an overtaking passenger car might be assumed to reach unconstrained speed, to the top of the summit is 1.3 mi. From the film, the average speeds and the travel time at these speeds from the lane to the summit were calculated as follows:

Vehicle Type	*Avg Time to Travel 200 ft (sec)*	*Avg Speed (mph)*	*Travel Time to Summit (min)*
Single cars	3.6	38	2.0
Trucks	6.1	22	3.5
Other slow vehicles (e.g., RVs)	5.2	26	3.0

The traffic stream classification includes 5.75 percent of cars that were able to overtake trucks in the climbing lanes and then save up to 1.5 min to the summit, and 6.4 percent of cars that overtook other slow vehicles, saving 1.0 min each. Expanding to the AADT, these savings aggregate to 13.8 hr/day or about 5,000 hr/year.

Although some literature assigns a value of time savings in such situations, it has been found in other studies that individual time savings of less than about 3 min are seldom, if ever, perceived by motorists and are of insignificant economic value. Even a generous assignment of $10/hr per automobile to the value of time on this highway would show a savings of only $50,000 per annum. Other user cost savings such as reduced fuel consumption and less vehicle wear and tear or external cost reductions such as reduced exhaust emissions, if calculated, would be so small that the level of accuracy in unit values for these factors would call the results into question.

Against any possible savings must be counted the cost of the five accidents described earlier that resulted in 13 injuries and 14 vehicles damaged in a 5-year period, directly related to the merging area at the end of the lane. Six other PDO accidents, which were not related to the merging area, occurred elsewhere within the limits of the climbing lane in the 5-year period; possibly some of these might have to be charged to the existence of the climbing lane.

One might therefore consider whether closure of the climbing lane could be justified on the basis of the accident experience and in view of the fairly low benefits obtained. It should be pointed out, however, that this analysis does not consider whether such closure might result in an increase in impatient drivers, leading to rasher driving behavior in the section between the existing climbing lane and the summit, and whether this would result in as many new accidents as might be avoided by the lane closure.

Length of the Climbing Lane

The distance required for cars to overtake slower vehicles can readily be estimated. It is assumed that all traffic reaches the beginning of the climbing lane at the speed of the slow platoon leader, that the driver of the car behind the leader uses a reaction time of 1 sec before accelerating to pass, that the acceleration rate up to normal car speed is 1.4 mph/sec, and that the car will have traveled 100 ft more than the vehicle being overtaken (i.e., from being 50 ft behind to being 50 ft ahead) before a merge can begin; finally, that 150 ft are added for the merging maneuver itself. Additional cars are assumed to follow at a spacing of 40 ft, which is reasonable at such low speeds.

For car speeds of 38 mph, truck speeds of 22 mph, and speeds of other show vehicles of 22 mph, the following results are obtained.

	Distance (ft) Required for Overtaking by—				
Platoon Leader	*One Car*	*Two Cars*	*Three Cars*	*Four Cars*	*Five Cars*
Truck	420	564	708	852	996
Other slow vehicle	432	651	870	1,089	1,308

This analysis indicates that, at this 800-ft-long climbing lane and at the speeds observed, only three cars can overtake a platoon-leading truck and only two cars can overtake somewhat faster-moving slow vehicles. Assuming the platoon size distribution observed in this study, this suggests that one or more cars will not be able to overtake a truck leading a platoon in 27 percent of all cases, and that one or more cars will not be able to overtake the leading vehicle in 37 percent of those platoons where a somewhat faster vehicle (light truck, RV, etc.) leads the platoon. When there are additional slow vehicles behind the leader, the situation will be aggravated; hence the percentages just calculated are the lowest possible, and actual opportunities to pass are even fewer.

From the film, it was found that 222 cars behind slow-moving vehicles were unable to overtake the platoon leaders (Table 3). Calculating benefits as was previously done for those cars that did overtake, annual time savings were estimated of about 7,250 vehicle-hours, if the climbing lane were long enough to permit this group of cars also to overtake and if they all were willing to travel at about 40 mph. Again, this total is an aggregate of individual savings of 1 to 1.5 min, having a monetary value of from 0 to a generous $70,000 per annum. However, savings might also accrue if the additional length reduces the accident rate; the descriptions of Accidents 4–8 suggest lack of overtaking opportunity within the length of the lane provided as a possible contributing cause.

The desirable length of uphill climbing lanes can be calculated by a process such as the preceding one, using appropriate traffic volumes and vehicle classifications, platoon size distributions, and speeds and accelerations that depend on length and amount of grade. The length in miles or minutes since the previous passing opportunity influences platoon sizes, but must also be considered with regard to the possibility of driver impatience.

In Oregon, for example, passing lanes excluding the tapers are required to be at least 1,000 ft long (*3*, p. 11), a length that exceeds the existing lane length on Meyers Grade only slightly, and would permit perhaps one additional car per long platoon to have a passing opportunity. Australia's recommended standard for a highway with design speed of 65 km/hr (40 mph) of about 450 m (1,475 ft) (*4*, p. 36) would, in the Meyers Grade case, increase the proportion of cars that can pass, but still leave a small fraction unable to do so. The Ontario and British Columbia minimum volume-related standards of 800 to 1,000 m (2,620 ft) (*4*, p. 32–33) would supply all the passing opportunities needed. However, in the specific case of Meyers Grade, provisions for a climbing lane longer than the existing one are unlikely to be economically feasible.

Relation to End of Grade or Next Passing Opportunity

As the analysis of time savings has shown, the economic value of a climbing lane that offers only 1 to 2 min of savings per vehicle to the point at which either all traffic speeds up or at which plentiful additional passing opportunities occur is probably negligible. Again, possible driver impatience because of a dearth of earlier passing opportunities might modify the result of such a calculation.

Sight Distance Ahead

Another potential problem at this site relates to the restricted sight distance ahead toward oncoming downhill traffic. The descriptions of Accidents 7 and 8 at this site refer to downhill vehicles appearing suddenly around the curve and contributing to the events that followed.

SUMMARY AND CONCLUSIONS

A search through accident records of northern and central California two-lane roads in hilly and mountainous terrain has revealed very few accidents related to the merging maneuver at the uphill end of climbing lanes. Of 157 accidents occurring within 0.1 mi of the upper end of the merging taper of 21 selected climbing lanes in a 5-year period, only 11 (7.0 percent) appear to have been directly caused by the need for vehicles to merge. Other circumstances, such as driving too fast for conditions, alcohol-influenced behavior, snow or ice conditions, illegal turns, and deer or rocks in the roadway, are primary factors in the majority of accidents at the type of locations studied.

More detailed analysis of the few accidents identified indicates a variety of reasons for their occurrence, although most involve last-chance attempts to complete an overtaking maneuver. Only one site with an accident pattern in the merging area could be found; here the relatively short length of the climbing lane on a long upgrade, which has probably built up driver frustrations and impatience, is a likely cause. Both at this site and at some others, a contributing factor may be the restricted sight distances beyond the merging area that prevent last-choice overtakers from seeing oncoming downhill traffic.

There is some evidence in the form of skidmarks and of observed brake applications and centerline encroachments that there are potentially hazardous conditions that do not result in accidents. When added to the few accidents that were reported, this suggests that guidelines for the length and location of climbing lanes should be formulated along the following lines:

1. The minimum length of climbing lanes should be calculated from an estimate of platoon lengths expected to be found at the site in question. The speeds of likely slow platoon leaders (trucks, buses, RVs, and cars hauling trailers) should be measured or calculated from speed data readily available in the literature *(8)*. By a simple computation, such as the one used for the Meyers Grade, the length required to permit all followers in a platoon to overtake the leader can then be calculated. Because not every platoon member can be provided an overtaking opportunity in cases of fairly heavy traffic, a rule can be adopted providing enough length for x percent of all followers to overtake, where x increases with the distance since the preceding overtaking opportunity. Alternatively, the Australian standards quoted in Table 1 may prove to be a suitable guideline. The Oregon and Washington minima of 1,000 ft may be adequate for low-volume roads, but do not appear to be sufficient for highways with AADT of more than about 5,000 and an appreciable proportion of slow-moving vehicles.

2. If the climbing lane terminates on an upgrade, the merging area should be located at a point beyond which traffic from the opposite direction can be seen for a sufficient distance to permit safe overtaking. However, if the climbing lane terminates at a point far enough beyond the crest of a grade to permit slow vehicles to resume normal speed, the urgency for overtaking by passenger cars diminishes, and the need for standard passing sight distance ahead is also less urgent. In any case, standard "No Passing Zone" signing and marking must be used and well maintained.

3. Benefits obtained from a climbing lane will vary directly with the distance of the lane either from the next good overtaking opportunity or from a point where slow vehicles can resume the same speed as fast ones, that is, the summit of a grade followed by good level or downhill alignment. If that distance is small, benefits are likely to be minor in economic terms, and may not exceed the annualized cost of providing the lane.

The second and third guidelines are supplemental to general guidelines on optimum placement of climbing lanes on long grades developed in prior research *(2)*.

Present standards for geometric design and installation of traffic control devices such as pavement marking and warning signs are quite adequate as shown by the low level of accidents. The problem of safety hazards in merging areas of climbing lanes on two-lane roads is therefore not a general problem at all. Occasional accidents occur in random fashion, as do so many traffic accidents generally. Seldom, only once in this study, can a location with an accident pattern be identified, and even then, the accident rate is not spectacularly high. Reviewing a few problem locations with the guidelines listed appears to be all that is necessary to assure continuation of the present good safety record.

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The author, of course, takes full responsibility for the accuracy of the final report.

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