Operational and Safety Effectiveness of Passing Lanes on Two-Lane Highways

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ABSTRACT

Passing lanes and short four-lane sections are installed to provide increased opportunities for passing slow-moving vehicles on two-lane highways. An operational and safety evaluation of these treatments was performed by using traffic operational field data collected at 15 sites and traffic accident data for 76 sites. It was found that passing lanes decrease the percentage of vehicles platooned on two-lane highways and that the magnitude of this benefit varies with passing-lane length, traffic volume, and the level of platooning upstream of the passing lanes. Passing lanes increase the rate of passing maneuvers on two-lane highways but have only a small effect on mean travel speeds. Passing lanes and short four-lane sections do not increase accident rates above the levels found on comparable untreated two-lane highways; in fact they probably improve safety.

An operational and safety evaluation (1) is presented of two closely related treatments used to improve traffic service on two-lane highways: passing lanes and short four-lane sections.

A passing lane is defined as an added third lane in one direction of a normally two-lane highway to provide opportunities for passing slow-moving vehicles where passing opportunities would otherwise be limited by sight distance and opposing traffic. A passing lane may be used either alone or as part of a series of passing lanes in alternating directions. Where sight distance is adequate, some agencies permit passing by vehicles traveling in the opposing direction to that of a passing lane, whereas other agencies prohibit all passing maneuvers by vehicles in the opposing direction.

Passing lanes in level or rolling terrain are a primary focus of this paper because they have not been evaluated extensively in the United States. However, added lanes of this type are also used extensively on steep grades in hilly or mountainous terrain, where they are generally known as truck climbing lanes. Climbing lanes located on grades long and steep enough to reduce trucks to crawl speeds have been evaluated more thoroughly than passing lanes in previous research and are therefore not addressed in this paper.

A short four-lane section is part of a four-lane highway, generally less than 3 mi long and bounded by two-lane sections at both ends. A short four-lane section on a normally two-lane highway could represent the ultimate design for a particular site or could represent the first step in staged construction of a four-lane highway. Whatever the purpose for which a short four-lane section was constructed, it provides additional passing opportunities and operates essentially as two passing lanes in opposite directions at the same location. A short four-lane section requires greater pavement and right-of-way width than a passing lane, but has the potential advantage that there is no need to permit vehicles traveling in either direction to cross the marked centerline in order to pass. Short four-lane sections are usually either undivided or divided with a narrow, flush median, although four-lane divided sections with a raised or unpaved median could operate in a similar manner.

Figure 1 shows a typical passing lane with passing prohibited in the opposing direction, a passing lane with passing permitted in the opposing direction, and a short four-lane section.

STUDY SITES

Passing lanes and short four-lane sections were evaluated by using data collected at selected sites in 12 states that participated in the study: Arkan-

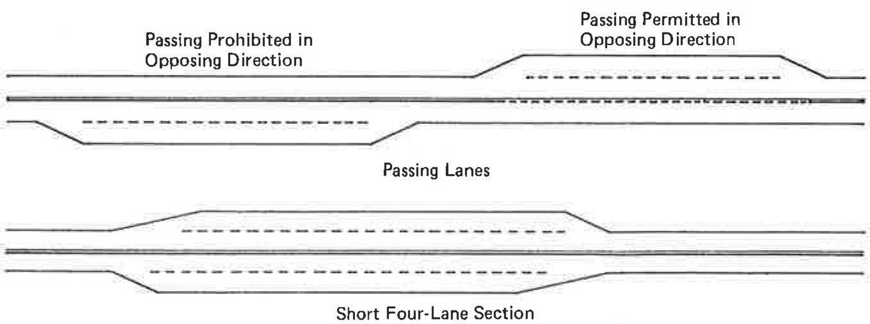

FIGURE 1 Typical passing lane and short four-lane sections.

sas, California, Kentucky, Michigan, Mississippi, Nevada, New York, Oklahoma, Oregon, Pennsylvania, Utah, and Washington. A traffic operational evaluation was based on field data collected at 12 passing-lane and 3 short four-lane sites. A safety evaluation was based on 1 to 5 years of accident data for each of 66 passing-lane and 10 short four-lane sites.

OPERATIONAL EVALUATION

An operational evaluation was performed for 12 passing lanes and 3 short four-lane sites by using traffic performance data collected in the field. The objectives of this evaluation were to determine the effectiveness of these treatments in improving traffic operations on two-lane highways and to determine the influence of traffic volume, geometrics, and treatment length on the operational effectiveness of the treatments.

Data Collection

The field data collection plan for passing lanes used automatic traffic data recorders (TDRs) at six locations and three manual observers. The TDRs were used to record traffic volumes, vehicle mix, speeds, accelerations, headways, and platooning characteristics. The manual observers counted passing maneuvers in both directions in the treated section, counted traffic conflicts or erratic maneuvers in the lane-drop transition area, and performed part of the vehicle classification by entering a code for each recreational vehicle into one of the TDRs. Figure 2 shows a typical data collection setup for a passing lane, including the location of TDR traps and the observers.

The data collection plan was structured to determine the effectiveness of passing lanes by a comparison of traffic operational conditions at three key locations: Location 1 (upstream of the passing lane); Location 3 (in the middle portion of the passing lane); and Location 5 (downstream). In addition, comparisons between Locations 5 and 6 (approximately 1 mile downstream from the passing lane) were intended to determine the rate at which operational benefits of the passing lane are lost downstream. The operational data collected at short four-lane sections were essentially equivalent to those collected at passing lanes, except that they were collected in four lanes rather than in three in the middle of the treated section.

Measures of Effectiveness

Three primary measures of effectiveness were used in this study to assess the operational benefits of passing lanes and short four-lane sections on two-lane highways. These measures were

- Traffic speed,
- Percentage of vehicles platooned, and
- Passing rate.

The mean speed and various percentiles of the speed distribution were used as measures of effectiveness. Speed descriptors were obtained separately for passenger cars, trucks and buses, recreational vehicles (RVs), unimpeded vehicles (free vehicles and platoon leaders) and the traffic stream as a whole.

A key measure of effectiveness in this study is the percentage of traffic traveling in platoons. Research by Messer (2) has found vehicle platooning to be more sensitive to traffic flow rate than mean speed, and the percentage of time spent following in platoons has been proposed as the primary criterion for defining level of service on two-lane highways in the current revision of the Highway Capacity Manual (HCM) (3).

Each vehicle recorded at a TDR trap was classified as a free vehicle, a platoon leader, or a platoon member. Each vehicle with a time headway of 4 sec or less was classified as a platoon member. The choice of the 4-sec headway criterion to define platooning was made after careful consideration of the criteria used by other researchers. The revised HCM procedures recommend a platoon definition based on a 5-sec headway (2). Morrall (4), a Canadian contributor to the revised HCM procedures, used a platoon definition based on a 6-sec headway. Hoban (5), who has conducted extensive operational research on two-lane highways and passing lanes in Australia, has recently recommended a 4-sec headway criterion. In this study, it was considered critical to avoid classifying a vehicle as platooned unless this was clearly the case. For this reason, the shortest of the criteria frequently cited in the literature, 4 sec, was selected.

The final measure of effectiveness used for the evaluation of passing lanes and short four-lane sections was the passing rate, defined as the number of completed passes per hour per mile in one direction of travel. The passing rate is an appropriate measure of effectiveness because passing lanes are intended to increase the passing rate above that which would occur on a normal two-lane highway.

Operational Analysis Results

A combined operational analysis of passing-lane and short four-lane sections was conducted. Each direction of travel in the short four-lane sections was treated as a separate passing lane, so the combined data for the operational analysis represent, in effect, 18 passing lanes.

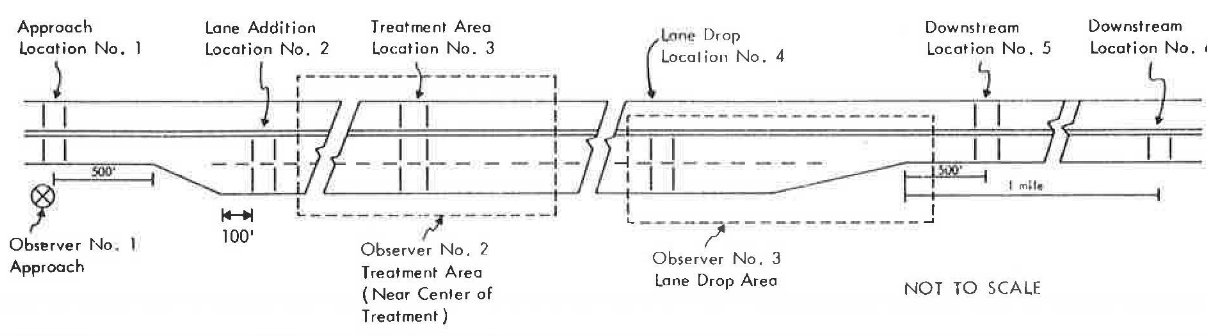

FIGURE 2 Locations of TDR traps and observers for data collection at passing lanes.

Up to 6 hr of operational data were collected at each study site. The traffic flow rates observed at the passing lane and short four-lane sites ranged from 26 to 710 vehicles per hour (vph) in the treated direction. However, the results reported in the following are not necessarily valid for flow rates above 400 vph because very little data at flow rates above that level were obtained. All the conclusions presented are statistically significant at the 95 percent confidence level unless otherwise stated.

Percentage of Vehicles Platooned

Passing lanes were found to reduce the percentage of vehicles that are members of platoons. Table 1 reveals the effect of passing lanes on vehicle platooning. The percentage of vehicles platooned decreased, on the average, from 35.1 percent immediately upstream of a passing lane to 20.7 percent within the passing lane. Immediately downstream of the passing lane, the percentage of vehicles platooned had increased to 29.2 percent, on the average, which is still 5.9 percent lower than the upstream level. This decrease in the percentage of vehicles platooned represents a major improvement in traffic service within a passing lane and a small improvement in traffic service downstream of a passing lane.

Table 1 also shows that the operational benefits from the introduction of a passing lane can vary greatly from site to site. These variations are even greater than those shown in the table when each hour of data from each site is examined separately. The prediction of these variations as a function of geometric and traffic operational variables will be addressed later.

An issue of interest to the evaluation of passing lanes is how far downstream the operational benefits of the added lane persist. It is expected, for example, that any reduction in platooning produced by a passing lane would gradually disappear downstream as faster vehicles overtake slower vehicles and are unable to find passing opportunities. Data were collected in the field approximately 1 mi downstream from each passing lane to determine the persistence of the reduction in platooning provided by a passing lane. Table 1 shows that on the average the percentage of vehicles platooned 1 mi downstream of a passing lane is still 3.5 percent lower than that upstream of a passing lane (31.6 versus 35.1 percent). However, the results obtained from the analysis of these data were inconclusive; the persistence of operational benefits from a passing lane appears to be highly dependent on the geometrics and traffic flow conditions in the downstream area.

The previous discussion has emphasized that this effectiveness of passing lanes varies over a range of values. Several predictive models were developed by using multiple regression analysis to investigate these variations in effectiveness as a function of geometric and traffic variables. A model was developed to predict the change in platooning from the upstream percentage of vehicles platooned and the passing-lane length. This model is

$$\Delta PL = 3.81 + 0.10 UPL + 3.99 LEN \quad (1)$$

where

- ΔPL = difference in percentage of vehicles platooned upstream and downstream of passing lane,
- UPL = percentage of vehicles platooned upstream of passing lane, and
- LEN = length of passing lane (mi).

This model explains 33 percent of the variation in the dependent variable (i.e., $R^2 = 0.33$). A positive value of ΔPL represents a reduction in platooning.

The percentage of vehicles platooned upstream of a passing lane (UPL) has the strongest correlation with ΔPL of any of the independent variables considered. UPL represents the combined influence of traffic volume, vehicle mix, and upstream geometrics on the traffic entering the passing lane. The use of UPL as a predictor of passing-lane effectiveness is quite appropriate because by using the revised HCM procedures for two-lane highways, UPL can be interpreted directly as the upstream level of service. The positive sign on the regression coefficient of UPL in Equation 1 indicates that the effectiveness

TABLE 1 Effect of Passing Lane on Percentage of Vehicles Platooned

		Percentage of Vehicles Platooned[b]				
Site	Avg Flow Rate (vph)	Immediately Upstream	Within Passing Lane[a]	Immediately Downstream	Downstream 1 mi	Upstream-Downstream Reduction (ΔPL)
1	140	27.4	14.6	18.7	23.0	8.7
2	560	61.9	44.6	57.1	51.5	4.8
3	120	28.0	11.0	21.7	21.3	6.3
4	120	43.4	33.3	40.7	41.8	2.7
5	80	11.7	11.0	8.0	10.7	3.7
6	150	26.7	13.4	25.5	25.0	1.2
7	300	41.2	34.4	36.7	40.9	4.5
8(NB)[c]	410	51.4	31.1	45.8	45.3	5.6
8(SB)[c]	415	46.1	28.7	42.6	-	3.5
9	130	34.2	18.5	31.4	25.0	2.8
10	150	24.1	15.4	22.0	21.6	2.1
11	35	9.2	2.8	8.0	10.7	1.2
12	300	49.1	22.2	37.3	41.6	11.8
13	305	39.0	21.6	44.1	47.2	-5.1
14(NB)[c]	280	41.7	24.1	-	-	-
14(SB)[c]	330	43.6	24.2	35.4	36.9	8.2
15(NB)[c]	340	50.9	22.8	38.4	-	12.5
15(SB)[c]	250	36.4	19.6	23.0	30.9	13.4
Avg[d]		35.1	20.7	29.2	31.6	5.9

[a]Combined data for right and left lanes in treated direction near center of passing-lane section.
[b]Platooned vehicles include following vehicles that are members of platoons but not platoon leaders.
[c]Short four-lane section; remainder of sections are passing lanes.
[d]Average of hour-by-hour data rather than site-by-site data tabulated above.

of a passing lane increases as the traffic entering the passing lane becomes more congested.

The model presented in Equation 1 also demonstrates that the effectiveness of a passing lane in reducing platooning also increases with passing-lane length. The influence of passing-lane length has been represented in Equation 1 as a linear term; however, it is expected conceptually that passing-lane length will have a nonlinear relationship to the effectiveness of a passing lane in reducing platooning, with shorter lanes being more effective per unit length than longer ones. The data currently available are not sufficient to model this nonlinear aspect of passing-lane length, but it merits further investigation.

Figure 3 shows the predictive model represented by Equation 1 and the variation of the reduction in the percentage of vehicles platooned as a function of the upstream percentage of vehicles platooned and the passing-lane length. For example, it can be seen that a 1-mi passing lane with 40 percent of the entering traffic platooned would be expected to reduce platooning by 11.8 percent.

Several additional models were used in an effort to find a model that explained more of the variance in ΔPL than Equation 1. It was found that when flow rate was added to the model presented in Equation 1, the resulting model explained 55 percent of the variance in ΔPL (i.e., $R^2 = 0.55$). This model is

$$\Delta PL = 7.64 - 0.04FLOW + 0.45UPL + 4.82LEN \quad \text{for } FLOW \le 400 \text{ vph} \qquad (2)$$

where FLOW is the flow rate in the treated direction in vehicles per hour and the remaining variables are as previously defined.

A conceptual drawback of Equation 2 is that the negative sign of the regression coefficient for flow rate implies an inverse relationship between flow rate and ΔPL, which seems counterintuitive; however, it should be noted that such an inverse relationship applies only if UPL and LEN are held constant. The unexpected negative sign for the coefficient of the flow rate term results because flow rate and UPL are strongly correlated with one another ($r = 0.89$, $p < 0.0001$). When two variables are so strongly correlated, it is best to use only one of them in a regression model. In this case, UPL is the better predictor of ΔPL and therefore Equa-

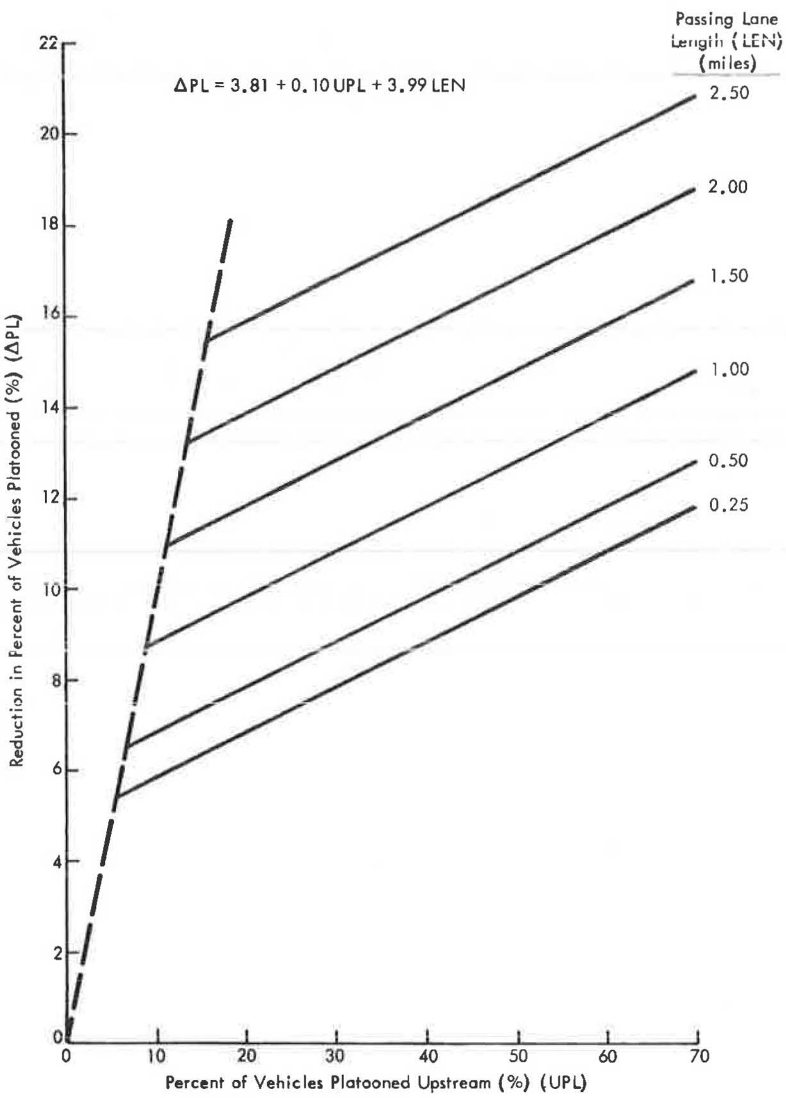

FIGURE 3 Relationship to predict reduction in percentage of vehicles platooned as a function of upstream percentage of vehicles platooned and passing-lane length.

tion 1 is recommended as the best predictive model for ΔPL.

Traffic Speed

An analysis of traffic speed was based on comparisons among the mean speed immediately upstream of the passing lane, within the passing lane, and immediately downstream of the passing lane. Mean speeds were found to be affected, on the average, only slightly by the presence of the passing lane. Mean speeds were approximately 2.2 mph higher within a passing lane than upstream of the lane and 0.9 mph higher downstream of a passing lane than upstream of it. These results indicate a small operational benefit in increased speeds because of the passing lane, although as suggested in the revised HCM, it appears that vehicle platooning is a more sensitive measure of traffic service than is mean speed.

The effect of a passing lane on traffic speed was found to vary widely from site to site. The variations in mean speed upstream and downstream of a passing lane can range from an increase of 8.3 mph to a decrease of 6.7 mph. This wide range of speed differences between upstream and downstream suggests that vehicle speeds are influenced more strongly by local geometrics at the upstream and downstream measurement sites than by the presence of a passing lane. Spot speeds are more sensitive to local geometrics than platooning measures because drivers can quickly adjust their speed in response to an external influence, whereas vehicle platoons require time to develop.

Several attempts were made to model the effect of passing lanes on mean speed, in a manner similar to Equations 1 and 2 for vehicle platooning. However, the relationships obtained from these analyses were considered to be unreliable for predicting the effectiveness of passing lanes, because the underlying data are influenced so strongly by local geometrics.

Passing Rate

The rate of completed passes per hour per mile was determined for all or a selected portion of each passing lane and short four-lane section. The following analysis is based on the assumption that where passing maneuvers were observed for only a portion of an added lane, the portion of the lane studied is representative of the lane as a whole.

Treated Direction

The passing rates in the treated direction were found to range from 0 to 219.3 passes per hour per mile. The passing rate was found to have a strong relationship to flow rate, represented by the following regression model:

$$PR = 13.0 + 0.223FLOW \text{ for } 50 \text{ vph} \leq FLOW \leq 400 \text{ vph} \quad (3)$$

where PR is the passing rate in the treated direction in completed passes per hour per mile. This model explains 47 percent of the variance in the dependent variable (i.e., $R^2 = 0.47$).

Figure 4 compares the passing rate predicted by Equation 3 for passing lanes with a corresponding relationship for one direction of a conventional two-lane highway adapted from a relationship presented in the 1950 HCM (6). Although the latter relationship is of questionable value and was omitted from the 1965 HCM (7), the comparison serves to illustrate that passing lanes provide much higher passing rates than would be possible on a conventional two-lane highway.

An improved regression model for predicting the passing rate in the treated direction was obtained by adding two independent variables--passing-lane length and upstream percentage of vehicles platooned--to the model. The revised model for passing rate in the treated direction is

$$PR = 0.127FLOW - 9.64LEN + 1.35UPL \text{ for } 50 \text{ vph} \leq FLOW \leq 400 \text{ vph} \quad (4)$$

This model explains 83 percent of the variance in the dependent variable ($R^2 = 0.83$).

The model presented in Equation 4 shows that the passing rate increases with increasing flow rate and with increasing upstream percentage of vehicles platooned. The model also shows that the passing rate decreases with increasing passing-lane length. This finding tends to confirm the hypothesis that the passing rate is highest near the beginning of a passing lane and decreases to a lower, steady-state level at some distance into the lane.

Untreated Direction

Passing rates in the untreated direction were also studied for the 12 passing-lane sites. Passing by opposing-direction vehicles is permitted at 6 of the 12 passing-lane sites and prohibited at the remaining 6.

The passing rate on passing lanes where passing is permitted in the untreated direction varied from 0 to 50.0 passes per hour per mile. At these sites, there is a strong linear relationship between the passing rate and the flow rate in the untreated direction. The regression model for this relationship is

$$OPR = -6.97 + 0.130FLOW \text{ for } 50 \text{ vph} \leq OFLOW \leq 400 \text{ vph} \quad (5)$$

where OPR is the passing rate in the opposing direction in passes per hour per mile and OFLOW is the flow rate in the untreated direction in vehicles per hour. This model explains 71 percent of the variation in the dependent variable (i.e., $R^2 = 0.71$).

Figure 4 shows that the passing rate in the untreated direction of a passing lane is substantially less than that in the treated direction but is higher than that for a conventional two-lane highway. Apparently more passes occur in the opposing direction of a passing lane than on a conventional two-lane highway because there are more passing opportunities available when the oncoming traffic can use two lanes rather than one.

The prohibition of passing in the opposing direction of a passing lane places that direction of travel at a distinct operational disadvantage. Despite the prohibition, a limited number of passing maneuvers do occur. The passing rates in the opposing direction ranged from 0 to 18.5 passes per hour per mile. No statistically significant relationship was found between opposing direction passing rate and flow rate for passing lanes where opposing-direction passing is prohibited.

SAFETY EVALUATION

A safety evaluation of the effectiveness of passing lanes and short four-lane sections was also performed. The purpose of this evaluation was to quantify the safety performance of these treatments in relation to comparable untreated sections and to detect any accident patterns or other safety prob-

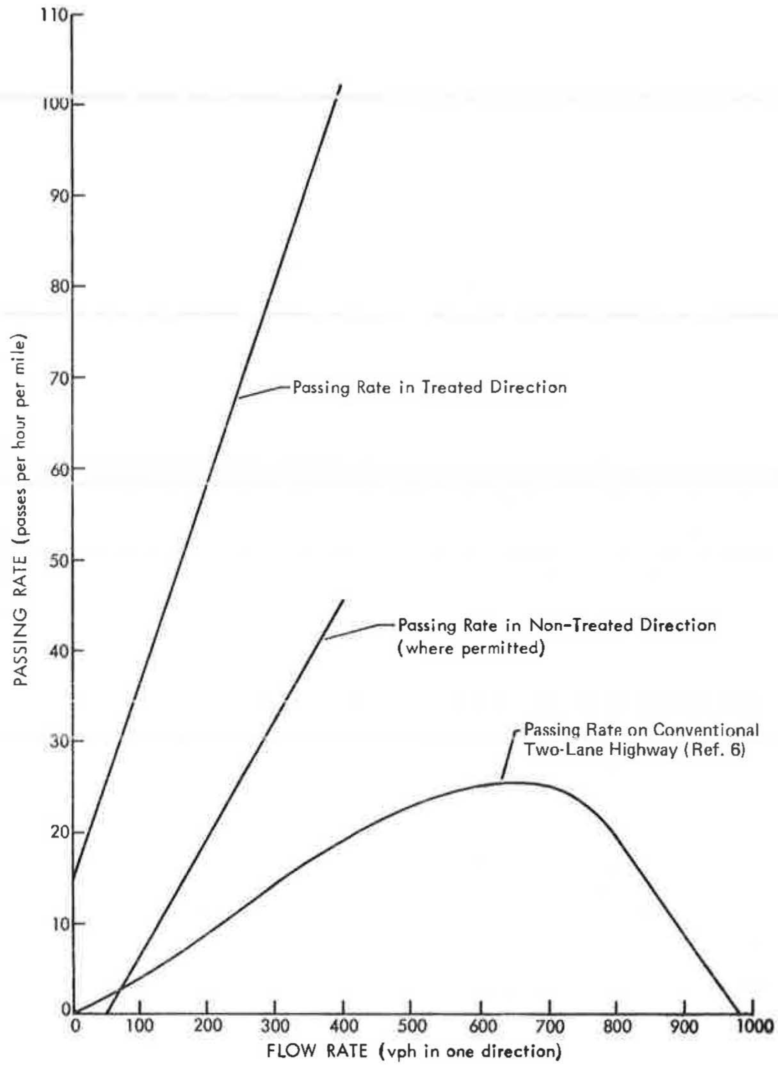

FIGURE 4 Passing rates in treated and untreated directions of passing lanes compared with conventional two-lane highways.

lems that might limit use of these treatments. Separate safety evaluations were performed for passing-lane and short four-lane sections.

Passing Lanes

Accident data were obtained from the participating states for a period of 1 to 5 years for each passing-lane site. The average length of the accident study period for the 66 passing-lane sites was 3.59 years. The results obtained from the analysis of these data are presented in the following paragraphs.

Comparisons Between Treated and Untreated Sites

Table 2 compares the mean accident rates for the treated and untreated directions of passing lanes and for comparable sections of untreated two-lane highway. The data presented indicate that the accident rates in passing lanes are slightly higher in the treated than in the untreated direction and that passing lanes have slightly lower accident rates than untreated two-lane highways. However, none of the differences between the means shown in Table 2 are statistically significant.

A matched-pair comparison was performed between 13 passing-lane sites and 13 corresponding untreated sites. The untreated sites were matched to the treated sites by the states that participated in the study. In all but two cases, the treated sites had a lower accident rate than the comparable untreated sites. The total accident rate of the passing-lane sites was, on the average, 38 percent less than that for comparable untreated sites and the fatal and injury accident rate was 29 percent less than that for comparable untreated sites. The observed difference in total accident rates was statistically significant at the 95 percent confidence level, but the difference in fatal and injury accident rates was not statistically significant.

Lane-Addition and Lane-Drop Transition Areas

A separate investigation was made of accidents in the lane-addition and lane-drop taper areas of passing lanes to determine whether there are any particular safety problems in those areas. Of the 305 accidents that occurred in the treated direction of passing lanes, 48 were found to occur in the first 800 ft of the passing lane and 51 in the final 800 ft. Figure 5 shows the distribution of accidents be-

TABLE 2 Comparison of Accident Rates for Passing Lanes and Untreated Two-Lane Highways

Type of Location	No. of Sites	No. of Accidents: Total	No. of Accidents: Fatal and Injury	Exposure (MVM)	Mean Accident Rate[a] (accidents/MVM): Total	Mean Accident Rate[a] (accidents/MVM): Fatal and Injury
Passing lane						
Treated direction[a]	66	305	133	271.0	1.13	0.49
Untreated direction	66	227	95	242.5	0.94	0.39
Both directions combined	66	532	228	513.5	1.04[b]	0.44[b]
Untreated two-lane highway (both directions combined)	13	430	226	273.5	1.57	0.83

Note: MVM = million vehicle miles.
[a]Including lane-addition and lane-drop transition areas.
[b]Based on average of accident rates for treated and untreated directions.

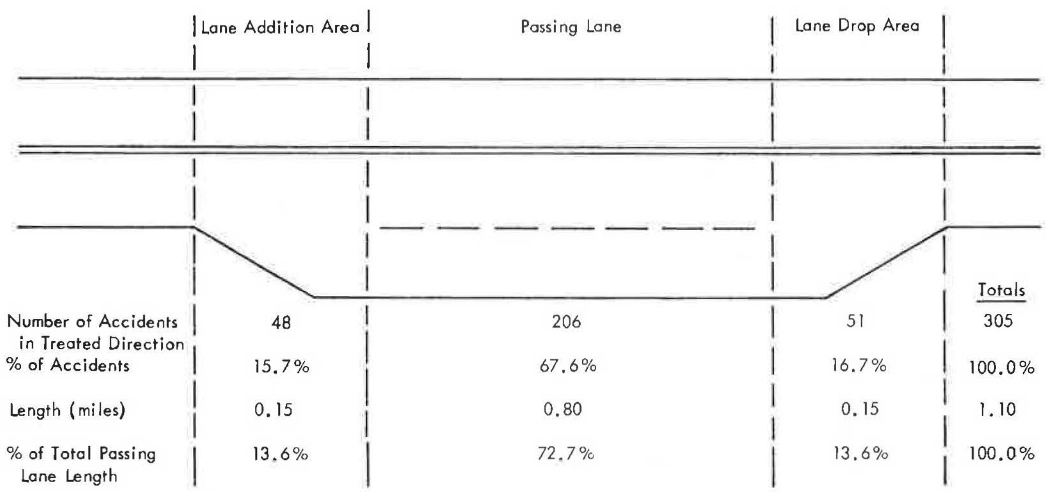

FIGURE 5 Distribution of accidents along a passing-lane section.

tween different areas of a typical passing lane. There is no indication that accidents are more likely in one transition area than in another. A slightly greater proportion of accidents occur in the transition areas than would be expected from their relative length alone, but the differences are not large. Thus, there is no indication of any marked safety problem in the lane-addition and lane-drop transition areas of passing lanes.

Studies of traffic conflicts and erratic maneuvers performed in the lane-drop transition areas of 10 passing-lane sites found no indication of safety problems associated with the transition area.

Although there is no evidence of a safety problem in lane-drop transition areas on the basis of the studies on accidents, traffic conflicts, and erratic maneuvers presented here, it is obvious that such transition areas should be carefully designed to prevent safety problems from developing. Many agencies that use alternating passing lanes either overlap them in the opposite direction or provide buffer areas between them to avoid a direct taper transition between passing lanes in opposite directions.

Cross-Centerline Accidents

Some agencies have been reluctant to install passing lanes on two-lane highways because of concern that such lanes might increase the likelihood of accidents between vehicles traveling in opposite directions, which are generally quite severe. In Table 3 the accident rates for cross-centerline accidents are compared for passing lanes with opposing passing prohibited, passing lanes with opposing passing per-

TABLE 3 Comparison of Cross-Centerline Accident Rates for Passing Lanes and Comparable Untreated Sections

Accident Severity Level	Passing-Lane Sections, Opposing Passing Prohibited: No. of Accidents	Exposure (MVM)	Accident Rate/MVM	Passing-Lane Sections, Opposing Passing Permitted: No. of Accidents	Exposure (MVM)	Accident Rate/MVM	Comparable Untreated Sections: No. of Accidents	Exposure (MVM)	Accident Rate/MVM
Fatal	6	234.7	0.026	5	278.8	0.018	7	273.5	0.026
Injury	15	234.7	0.064	12	278.8	0.043	39	273.5	0.143
Property damage only	10	234.7	0.043	14	278.8	0.050	28	273.5	0.102
Total	31	234.7	0.133	31	278.8	0.111	74	273.5	0.271

Note: MVM = million vehicle miles.

mitted, and comparable untreated sections. Cross-centerline accidents are defined here as all accidents that involve vehicles traveling in opposite directions; such accidents are predominantly head-on and opposing-direction sideswipe collisions. No substantial differences in accident rate were found at any severity level between passing-lane sections with opposing passing permitted and those with opposing passing prohibited, but both types of passing-lane sections have lower accident rates than do untreated two-lane highways. Thus, the provision for passing by vehicles traveling in the opposing direction to that of a passing lane does not appear to lead to any safety problems at the types of sites and the flow rate levels (up to 400 vph) where it has been permitted by the participating states.

Left-Turning Accidents

Accidents involving left-turning vehicles are a potential safety problem on passing-lane sections. A vehicle turning left into an intersection or driveway from the treated direction of a passing-lane section is in an exposed position if it must slow or stop in the left lane, which is normally the higher-speed lane, and yield to opposing traffic before completing a turn. However, it was found that only 8 accidents on the 66 passing-lane sections involved vehicles turning left from the treated direction. These accidents were not very severe: none were fatal, two were injury accidents, and six were property-damage-only accidents. Two of the eight accidents involved intersections and the remaining six were presumably driveway-related. On the other hand, the sample of untreated two-lane highways experienced 29 left-turn accidents of which none were fatal, 18 were injury accidents, and 18 were property-damage-only accidents. The untreated sections experienced virtually the same total travel as the treated direction of the passing-lane sections (273.5 and 271.0 million vehicle-mi of travel, respectively), so the two types of overall exposure data are comparable. Unfortunately, no complete data on left-turn volumes or the number of driveways and intersections are available to permit more precise exposure measures to be used. However, on the basis of the available data, there does not appear to be a safety problem associated with left-turn accidents in passing-lane sections.

Short Four-Lane Sections

The safety evaluation of short four-lane sections was based on accident data collected for nine short four-lane sections in three states--New York, Oregon, and Washington. Accident data were also available for six untreated two-lane highway sections located near all but one of the nine treated sections.

Comparison Between Treated and Untreated Sites

In Table 4 the overall accident experience for the treated and untreated sites is compared. The total accident rate for short four-lane sections is approximately 34 percent less than that for the untreated sections and the fatal and injury accident rate is 43 percent less, although these differences are not statistically significant. The accident rates for short four-lane sections and untreated sections presented in Table 4 are of comparable magnitude; the accident rates for passing lanes and untreated sections, respectively, are presented in Table 2.

A matched-pair comparison of accident rates for six short four-lane sections and six comparable untreated sections was also performed. In all but one case, the short four-lane sections had lower accident rates than the corresponding untreated sections. The total accident rate of the treated sites was 53 percent lower than that of the comparable untreated sites and the fatal and injury accident rate was 52 percent lower. Because of the small number of sites available, the mean difference in accident rates, although substantial, is not statistically significant for either total accidents or fatal and injury accidents.

Cross-Centerline Accidents

Table 5 shows that the rates for cross-centerline accidents on short four-lane sections are generally less than half of the rates for the same type of accidents on the comparable untreated sections.

CONCLUSIONS

Passing lanes and short four-lane sections were found to provide substantial operational benefits

TABLE 4 Comparison of Accident Rates for Short Four-Lane Sections and Comparable Two-Lane Highways

		No. of Accidents			Accident Rate/MVM	
Type of Location	No. of Sites	Total	Fatal and Injury	Exposure (MVM)	Total	Fatal and Injury
Short four-lane section	9	106	69	89.6	1.18	0.77
Comparable two-lane highway	6	250	189	139.4	1.79	1.36

TABLE 5 Comparison of Cross-Centerline Accident Rates for Short Four-Lane and Comparable Untreated Sections

	Short Four-Lane Sections			Comparable Untreated Sections		
Accident Severity Level	No. of Accidents	Exposure (MVM)	Accident Rate/MVM	No. of Accidents	Exposure (MVM)	Accident Rate/MVM
Fatal	3	89.6	0.033	1	139.4	0.007
Injury	10	89.6	0.112	45	139.4	0.323
Property damage only	4	89.6	0.045	10	139.4	0.072
Total	17	89.6	0.190	56	139.4	0.402

when used as an operational treatment on two-lane highways. Both types of added lanes increase the passing rate in the treated direction to several times the passing rate that would occur on a conventional two-lane highway. By using Equation 4, passing rates in passing lanes and short four-lane sections can be predicted as a function of flow rate, length of treated section, and upstream percentage of vehicles platooned.

The percentage of vehicles platooned is reduced by nearly half (from 35.1 to 20.7 percent of vehicles following in platoons) within a passing lane. The percentage of vehicles platooned immediately downstream of a passing lane is 6 percent less than the upstream value (29.2 versus 35.1 percent); the persistence of these downstream benefits is variable and highly dependent on the characteristics of particular sites. These results imply that at 250 vph (a typical flow rate for a passing lane on a two-lane highway) if 90 vehicles are following in platoons upstream of a passing lane during a given hour, only 50 vehicles will be following in platoons within the passing lane and only 75 vehicles will be following in platoons immediately downstream of the passing lane. The operational benefits of passing lanes can persist for several miles downstream from the treated section.

The reduction in platooning from upstream to downstream of a passing lane can be predicted as a function of the upstream percentage of vehicles platooned and the length of the added lane by using Equation 1. Further research is being conducted through computer simulation of traffic operations on two-lane highways with and without passing lanes. This research will address questions of fundamental importance to designers, including the optimal length and frequency of passing lanes under different conditions of traffic flow and terrain.

A safety evaluation found that the installation of a passing lane on a two-lane highway does not increase the accident rate and in fact probably reduces it. No unusual safety problems were found to be associated with either lane-addition or lane-drop transition areas. The rate of accidents involving vehicles traveling in opposite directions was found to be the same or lower on passing-lane sections than on untreated two-lane highways at all severity levels, even for passing lanes where passing by opposing-direction vehicles is permitted. No safety problems associated with vehicles making left turns from the treated direction of a passing lane were found.

A substantially lower accident rate was found for short four-lane sections than for comparable untreated two-lane highways. The accident rates involving vehicles traveling in opposite directions on short four-lane sections were generally less than half of the rates found on comparable untreated sections. Because of the small sample size available for short four-lane sections, the statistical significance of these conclusions could not be demonstrated.

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