Effective Use of Passing Lanes on Two-Lane Highways

DOUGLAS W. HARWOOD, CHRIS J. HOBAN, AND DAVEY L. WARREN

Passing lanes have been found to be effective in improving overall traffic operations on two-lane highways. Many of the traffic operation problems on rural two-lane highways result from the lack of passing opportunities due to limited sight distance and heavy oncoming traffic volumes. Passing lanes can provide an effective method for improving traffic operations on two-lane highways at a lower cost than required for constructing a four-lane highway. The paper presents guidelines for effectively locating, designing, signing, and marking passing lanes to improve traffic operations. A procedure for estimating the operational effectiveness of passing lanes in terms of improved service is presented. The paper also presents an evaluation of the effectiveness of passing lanes in reducing accidents on two-lane highways.

A passing lane is an added lane provided in one or both directions of travel on a conventional two-lane highway to improve passing opportunities. This definition includes passing lanes in level or rolling terrain, climbing lanes on grades, and short four-lane sections. The length of the added lane can vary from 1,000 feet to as much as three miles. Figure 1 illustrates a plan view of a typical passing lane section.

Many of the traffic operational problems on rural two-lane highways result from the lack of passing opportunities due to limited sight distance and heavy oncoming traffic volumes. Passing lanes provide an effective method for improving traffic operations on two-lane highways by providing additional passing opportunities at a lower cost than required for constructing a four-lane highway. This lower-cost approach is appropriate because there is a growing backlog of rural roads requiring improvement, and the funds are simply not available to four-lane every two-lane highway that experiences poor levels of service.

FUNCTIONS OF PASSING LANES

Passing lanes have two important functions on two-lane rural roads:

- To reduce delays at specific bottleneck locations, such as steep upgrades where slow-moving vehicles are present and
- To improve overall traffic operations on two-lane highways by breaking up traffic platoons and reducing delays caused by inadequate passing opportunities over substantial lengths of highway

The first function, to reduce delays at bottleneck locations, has been recognized for some time, and guidelines for the provision of climbing lanes on grades have been established. The second function, to improve overall traffic operations, has evolved more recently, particularly as a result of the lack of funds for major road improvements. In practice, many passing lanes perform both functions, and it is often difficult to make a clear operational distinction between the two. The distinction is important, however, in planning and design. The evaluation of a climbing lane considers only the bottleneck location, with the objective of improving traffic operations at the bottleneck to at least the same quality of service as adjacent road sections. For passing improvements, on the other hand, the evaluation should consider traffic operations for an extended road length, typically 5 to 50 miles. Furthermore, the location of the passing improvement can be varied and selecting an appropriate location is an important design decision.

LOCATION AND CONFIGURATION

When passing lanes are provided at an isolated location, their function is generally to reduce delays at a specific bottleneck, and the location of the passing lane is dictated by the needs of the specific traffic problem encountered. Climbing lane design guidelines, for example, usually call for the added lane to begin before speeds are reduced to unacceptable levels and, where possible, to continue over the crest of the grade so that slower vehicles can regain some speed before merging. Requirements for sight distance and taper lengths further define the location of such lanes. In some cases, construction of a climbing lane over the full length of a grade may be too expensive, and the use of shorter lanes over part of the grade may be considered. Recent research at the University of California (*1*) suggests that single short climbing lanes of approximately 1,500 feet near the midpoint of the grade, or two such lanes at the one-third and two-thirds points, are cost-effective methods for providing passing opportunities on long sustained grades. The location of a climbing lane drop on an upgrade section has been found to produce no adverse safety problems, provided sight distance is adequate (*2*).

When passing lanes are provided to improve overall traffic operations over a length of road, they are often constructed at regular intervals. The designer can choose from a number of alternative configurations (*3*), as illustrated in figure 2.

D. W. Harwood, Midwest Research Institute, 425 Volker Boulevard, Kansas City, Mo. 64110. C. J. Hoban, Australian Road Research Board, 500 Burwood Highway, Vermont South 3133, Victoria, Australia. D. L. Warren, Federal Highway Administration, 6300 Georgetown Pike, McLean, Va. 22101.

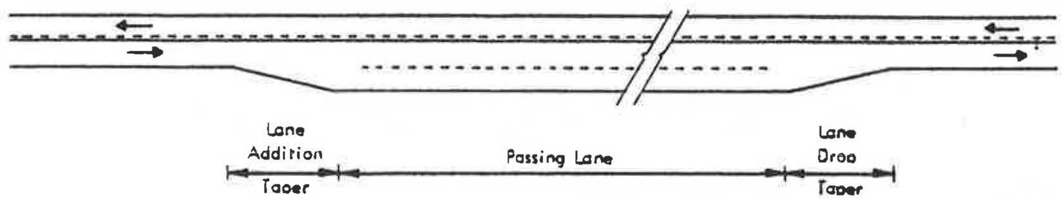

FIGURE 1 Plan view of typical passing lane section.

Factors that should be considered in choosing the location and configuration for passing lanes are discussed below.

Location

A primary objective in choosing the location for a passing lane should be to minimize construction costs, subject to other constraints. Data from several states indicate that the cost of constructing a passing lane can vary from $200,000 to $750,000 per mile, depending on terrain. Climbing lanes in mountainous areas can cost as much as $1,800,000 per mile. Thus, the choice of a suitable location for a passing lane may be critical to its cost-effectiveness. A construction cost profile indicating the longitudinal variation of construction cost per mile along the road can be a useful tool in selecting passing lane locations.

The passing lane location should appear logical to the driver. The value of passing lanes is more apparent to drivers at locations where passing sight distance is restricted than on long tangent sections that already provide good passing opportunities. In some cases, a passing lane on a long tangent may encourage slow drivers to speed up, thus reducing the passing lane effectiveness. At the other extreme, highway sections with low-speed curves are not appropriate for passing lanes, since passing may be unsafe.

The passing lane location may be on a sustained grade or on a relatively level section. If delay problems on a grade are severe, the grade will usually be the preferred location for a passing lane. However, if platooning delays exist for some distance along a road, locations other than upgrades should also be considered for passing lanes. While speed differences between vehicle types are often greater on upgrades than on level or rolling sections, particularly if heavily loaded trucks are present, construction costs and constraints may be greater at such locations. Some types of slow vehicles, such as recreational vehicles, are not slowed by upgrades as dramatically as heavy trucks; passing lanes in rolling terrain may provide opportunities to pass such vehicles that are just as good as the opportunities provided by passing or climbing lanes on upgrades. Passing lanes are also effective on level terrain where the demand for passing opportunities exceeds supply.

The passing lane location should provide adequate sight distance at the lane-addition and lane-drop tapers.

The location of major intersections and high-volume driveways should be considered in selecting passing lane locations, to minimize the volume of turning movements on a road section where passing is encouraged. Low-volume intersections and driveways do not usually create problems in passing lanes. Where the presence of higher-volume intersections and driveways cannot be avoided, special provisions for turning vehicles should be considered. The prohibition of passing by vehicles travelling in the opposing direction should also be considered on passing lane sections with high-volume intersections and driveways.

Locations with other physical constraints, such as bridges and culverts, should be avoided if they restrict the provision of a continuous shoulder.

Passing lanes can also be constructed as part of realigning a road segment that has safety problems.

Configuration

Separated or adjoining passing lanes (shown as (c) through (f) in figure 2) are often used in pairs, one in each direction, at regular intervals along a two-lane highway.

Where pairs of adjoining passing lanes are used and passing by opposing direction vehicles is prohibited, the use of configuration (e) in figure 2 has the advantage of building platoons before the passing lane, whereas the reverse configuration tends to rebuild platoons more quickly after the passing lane. This configuration is also preferred because the lane-drop areas of the opposing passing lanes are not located adjacent to each other.

Transitions between passing lanes in opposing directions should be carefully designed; intersections, bridges, two-way left-turn lanes, or painted medians can often be used effectively to provide a buffer area between opposing passing lanes.

Alternating passing lanes (shown as (g) and (h) in figure 2) are sometimes appropriate where a wide pavement is already available. However, the provision of passing lanes over 50 percent of the road length is probably excessive. Drivers may also feel unduly constrained when passing is prohibited on the other 50 percent of the road length if sight distance is good and traffic volumes are low.

Short, four-lane sections, both divided and undivided, are particularly appropriate where the ultimate design is for the highway to have four lanes. Construction of short, four-lane sections at the least expensive locations can provide a substantial proportion of the benefits of the ultimate design for a relatively small proportion of the total cost, particularly if major bridge work or right-of-way acquisition can be avoided. This staged four-laning will generally return a high benefit-cost ratio, while economic justification for the remaining stages will increase with increasing traffic volumes in future years. Where the ultimate design is uncertain or the need for it is many years away, however, the use of lower cost options should be considered.

Overlapping passing lanes (shown as (i) and (j) in figure 2) are often used at crests where a climbing lane is provided on each upgrade.

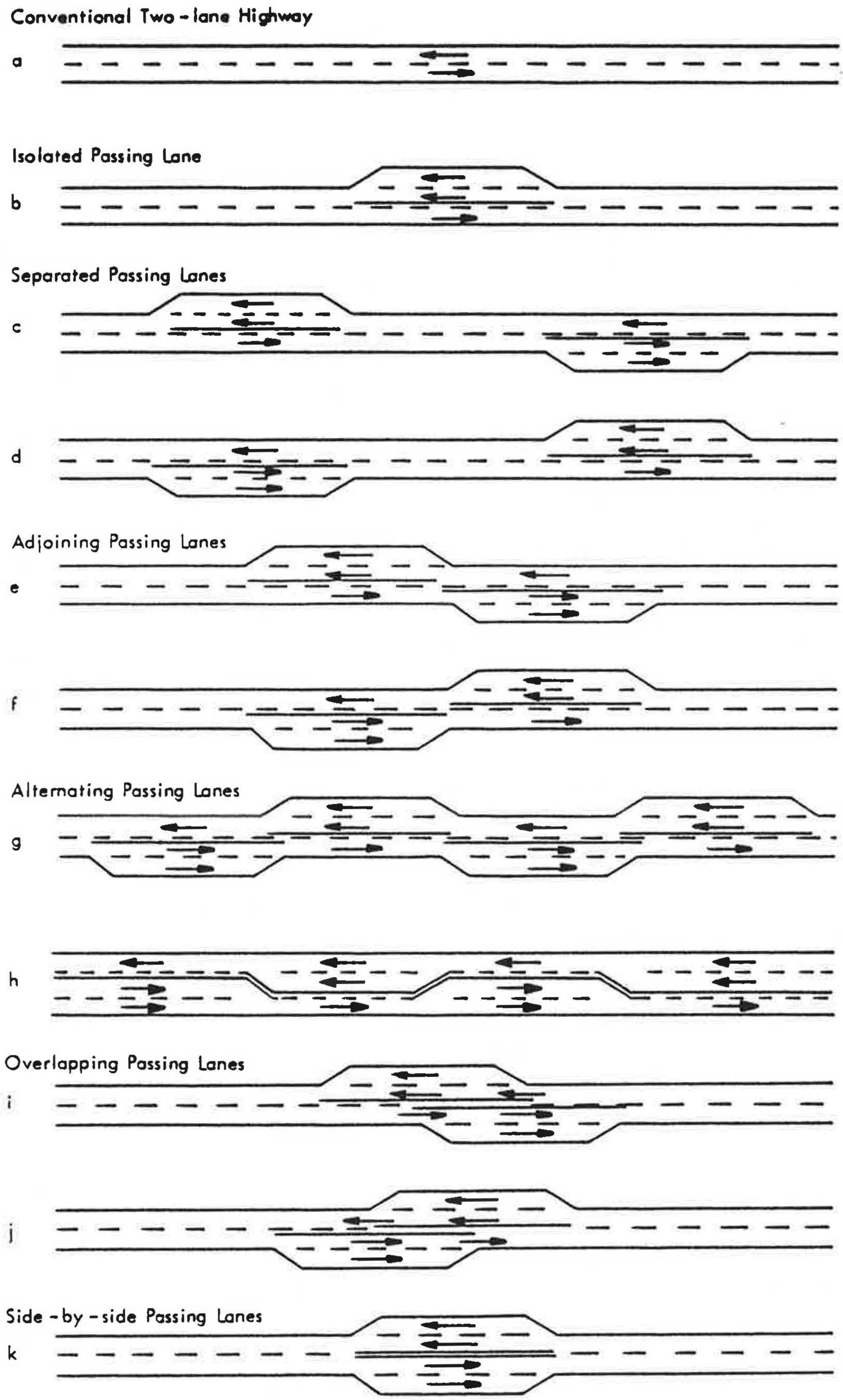

FIGURE 2 Alternative configurations for passing lanes.

GEOMETRIC DESIGN

The length of the passing lane, the lane and shoulder widths, and the lane-addition and lane-drop taper designs should be considered in the geometric design of passing lanes. The following guidelines for geometric design were developed by Harwood and Hoban (*5*).

Passing lanes should generally be from 0.5- to 1.0-mile long, excluding tapers. Passing lanes less than 0.5-mile long are usually not effective in creating additional passing opportunities, and passing lanes over 1.0-mile long are usually not cost-effective (*5, 6*). The choice of an optimal design length for passing lanes on two-lane highways should be a function of the traffic flow rate and is addressed in a later section of this paper.

The lane widths in a passing lane section usually should not be narrower than the lane widths on the adjacent sections of two-lane highway; 12-foot lane widths are desirable. It is also desirable for passing lane sections to have a minimum four-foot shoulder width on either side of the highway. Wherever possible, the shoulder width in a passing lane section should not be narrower than the shoulder width on the adjacent sections of two-lane highway.

The lane-addition and lane-drop transition areas at the beginning and end of a passing lane should be designed to encourage safe and efficient traffic operations. Many highway agencies have used relatively short lane-addition and lane-drop tapers at passing lanes. However, the use of longer tapers should be encouraged to minimize traffic conflicts and to get the greatest operational benefit from the investment in passing lanes.

The lane-drop taper at the downstream end of a passing lane should be designed in accordance with the requirements for lane reduction transitions set by the FHWA Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD), Section 3B-8. The recommended geometric configuration is to terminate the right lane with a lane-drop taper and merge the traffic from both lanes into a single lane. In a few cases, such as alternating passing lanes on a three-lane pavement of constant width, dropping the left lane is appropriate. The lane-drop taper length should be computed from the formula $L = WS$, where L is the taper length in feet, W is the width of the dropped lane in feet, and S is the prevailing off-peak 85th percentile speed in miles per hour (mph). At the termination of a 12-foot lane, the required taper length for a 60-mph prevailing speed is 720 feet. A wide shoulder is desirable at the lane-drop taper to provide a recovery area in case drivers encounter a merging conflict.

There is no MUTCD requirement for the length of the lane-addition taper at the upstream end of a passing lane. The diverge maneuver does not require as much length as the merge maneuver, but a good lane-addition transition design is needed for effective passing lane operations. The recommended length for a lane-addition taper is half to two-thirds of the length of a lane-drop taper, or 360 to 480 ft in the example of the 60-mph design speed presented above.

Passing lanes are most effective if the majority of drivers enter the right lane at the lane-addition transition and use the left lane only when passing a slower vehicle. Little or no operational benefit is gained from passing lanes if most drivers continue in the left lane. The geometric design of the lane-addition transition area, together with appropriate signing and marking (discussed below) should encourage drivers to enter the right lane of the passing lane section.

Safe and effective passing lane operations require adequate sight distance on the approach to both the lane-addition and lane-drop tapers. Inadequate sight distance in advance of the lane-addition taper may result in lack of readiness by vehicles wishing to pass, so that some of the length of the passing lane is wasted. When sight distance approaching the lane-drop taper is limited, vehicles may merge too early or too late, resulting in erratic behavior and poor use of the passing lane. Therefore, passing sight distance appropriate for the speed of the highway on the approach to each taper is recommended. Above-minimum passing sight distance in the taper areas is desirable.

TRAFFIC CONTROL DEVICES

The signing and marking of passing lanes is partially addressed in the MUTCD (*4*), which indicates the appropriate centerline markings for passing lanes and the signing and marking of lane-drop transitions areas. The following discussion extends the MUTCD criteria to provide a consistent set of traffic control devices for use at passing lanes, as illustrated in figure 3. The recommended signing and marking practice presented here were developed by Harwood and Hoban (*5*) from review of the practices of 13 states (*6*) and the practices used in Australia and Canada (*3*). The recommended practice is presented here not to suggest that it should be adopted in precisely this form by every highway agency, but to illustrate the types of signs and markings that are needed for effective operation of passing lanes.

Signing

Signing is needed to convey information to drivers at three locations at passing lane sites:

- In advance of the passing lane,
- At the lane addition, and
- In advance of the lane drop.

Advance Signing

A sign with the legend PASSING LANE ½ MILE should be placed 0.5 mile in advance of each passing lane. This sign provides advance notice of the passing lane to the drivers of both slow-moving vehicles and following vehicles so that they can prepare to make effective use of the passing lane. Additional advance signs are desirable two to five miles in advance of a passing lane. Such advance signing may reduce the frustration and impatience of drivers following a slow-moving vehicle because they know they will soon have an opportunity to pass. Driver frustration and impatience when following slow-moving vehicles has been shown to be a potential safety problem on two-lane highways. Hostetter and Seguin (*7*) found, for example, that when forced to follow a slow-moving vehicle for up to 5 miles, almost 25 percent of drivers passed illegally in a no-passing zone.

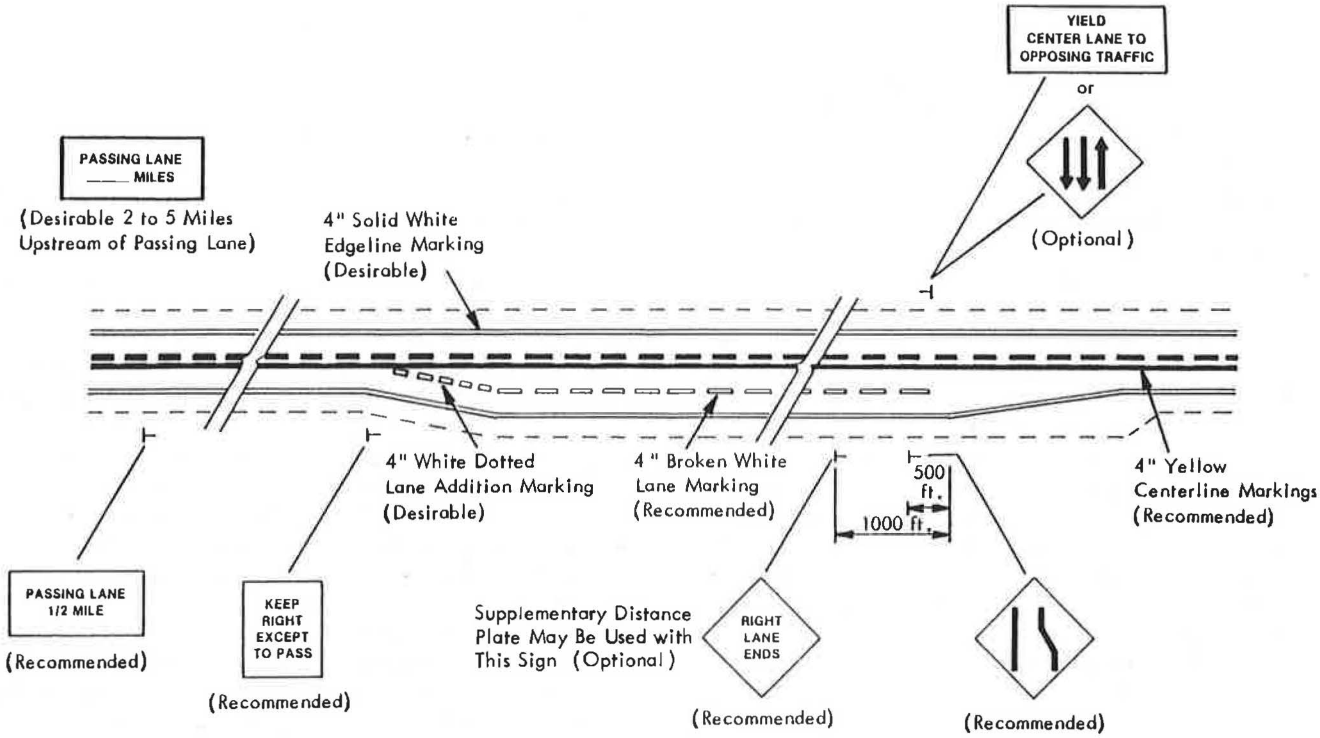

FIGURE 3 Recommended signing and marking practices for passing lanes.

Lane-Addition Signing

A black-on-white regulatory sign with the legend KEEP RIGHT EXCEPT TO PASS should be placed at the beginning of the lane-addition taper. This sign, in conjunction with the geometrics and pavement markings at the lane-addition taper, informs drivers of the beginning of the passing lane and encourages them to enter the right lane unless they are immediately behind a vehicle they wish to pass. An acceptable alternative legend for this sign is SLOWER TRAFFIC KEEP RIGHT, although this legend is not preferred because it provides less definite instructions to drivers. Sign legends that refer specifically to trucks, such as TRUCKS USE RIGHT LANE, are not recommended because they appear to exclude other vehicle types, such as slow-moving recreational vehicles and passenger cars, which should also be encouraged to use the right lane.

Lane-Drop Signing

The MUTCD requires a black-on-yellow warning sign, either a symbol sign or a text sign, in advance of a lane drop. According to MUTCD table II-1, for a prevailing speed of 60 mph, a single warning sign should be placed 775 feet in advance of a decision point that requires a high degree of judgment, such as a lane-drop merging maneuver. Many highway agencies use two warning signs in advance of the lane-drop transition areas of passing lanes, and this practice is recommended. The first advance warning sign with the legend RIGHT LANE ENDS, should be located 1,000 feet in advance of the lane-drop taper. This sign may carry a supplemental distance plate (for example, 1,000 FEET) below the sign. The second advance warning sign should be the lane reduction transition symbol sign and should be located 500 feet in advance of the lane-drop taper.

Signing for Opposing Traffic

Highway agencies that generally provide signing for passing and no-passing zones on conventional two-lane highways, including the DO NOT PASS sign, the PASS WITH CARE sign, and the pennant-shaped NO PASSING ZONE sign, usually continue this practice in the opposing direction of travel at passing lane sites. Where passing by vehicles travelling in the opposing direction is permitted, some agencies use a regulatory sign specifically appropriate to passing lanes, such as YIELD CENTER LANE TO OPPOSING TRAFFIC, in place of the PASS WITH CARE sign. An alternative sign for use in the opposing direction to a passing lane is the three-arrow sign used in Australia, which is illustrated in figure 3. This sign does not identify whether passing by vehicles travelling in the opposing direction is permitted or prohibited, but it does inform drivers that there are two lanes of oncoming traffic.

Marking

A passing lane section with two lanes in one direction of travel and one lane in the opposite direction of travel should be marked in accordance with MUTCD figure 3-2. A yellow centerline marking should be used to separate the lanes normally used by traffic moving in opposite directions. A broken white lane line is used to separate traffic in lanes normally moving in the same direction. Pavement edge lines are desirable on both sides of the highway in passing-lane sections to guide drivers and to delineate the boundary between the pavement and shoulder.

Passing by vehicles travelling in the opposing direction to a passing lane may be either permitted or prohibited, as illustrated in MUTCD figure 3-2. A study by Harwood and St. John (*6*) found no difference in cross-centerline accident rates between passing lane sections where passing in the opposing direction was prohibited and passing lane sections where passing in the opposing direction was permitted where adequate sight distance was available. Therefore, passing by opposing-direction vehicles may be allowed where sight distance is adequate. This finding indicates that passing lanes where passing by opposing direction vehicles is permitted do not have safety problems of the type that occurred many years ago on three-lane highways with center lanes available for unrestricted use by vehicles travelling in either direction. Passing zones should be marked for the opposing direction of travel in passing lanes where warranted by the same criteria used in marking normal two-lane highways, specified in MUTCD Section 3B-5. For a 60-mph prevailing speed, a no-passing zone is warranted in the opposing direction of travel where sight distance is less than 1,000 feet.

It is not a desirable practice to prohibit passing by vehicles travelling in the opposing direction at all passing lane sites, because this unnecessarily reduces the level of service in that direction of travel. Prohibition of passing in the opposing direction at all passing lanes, regardless of sight distance, may be counterproductive to improved safety, since some drivers travelling in the opposing direction may be tempted to pass despite the prohibition in areas of good sight distance. Some agencies may choose to institute a site-by-site review of passing lanes and prohibit opposing direction passing at particular sites on the basis of unusual geometrics, roadside development, high traffic volumes, or similar factors, in addition to limited sight distance. The prohibition of passing by vehicles travelling in the opposing direction is particularly appropriate at sites with roadside development that generates frequent left-turn movements from the left lane of the treated direction in the passing lane section.

Lane-Addition Markings

The MUTCD does not provide any specific guidance for marking a lane-addition transition area. The recommended pavement marking scheme is illustrated in figure 3. The use of a pavement edge marking in the lane-addition transition area is recommended. A white dotted marking tapering across the left lane immediately prior to the beginning of the lane line is recommended. Several highway agencies have found this marking to be effective in guiding most drivers into the right lane. Drivers who desire to pass immediately upon entering the passing lane are permitted to cross the dotted marking.

Lane-Drop Markings

Pavement markings in the lane-drop transition area should be provided in accordance with MUTCD Section 3B-8, as illustrated in MUTCD figure 3-10. For a 60-mph prevailing speed, the broken white lane line should be discontinued 580 feet prior to the beginning of the lane-drop taper. The use of a pavement edge marking in the lane-drop transition area is recommended.

OPERATIONAL EFFECTIVENESS

The operational effectiveness of passing lanes on two-lane highways has been evaluated extensively in Australia, Canada, and the United States. The results of the recent evaluation of passing lanes in the United States are summarized in the following discussion to provide guidance on where passing lanes should be used and what operational benefits should be expected. International research has also demonstrated the effectiveness of passing lanes. Australian research has resulted in the development of minimum-volume warrants for passing lanes based on average daily traffic (ADT) volumes and percent of highway length providing passing opportunities over the previous 2 to 6 miles (*8*). Canadian research has developed a concept based on the percentage of highway length with "assured" passing opportunities to determine where passing lanes are needed (*9, 10*). Summaries of these results have also been presented by Harwood and Hoban (*5*).

The research approach used in the United States has focused on tying the operational effectiveness of passing lanes to the levels of service for two-lane highways used in Chapter 8 of the 1985 Highway Capacity Manual (HCM) (*11*). These levels of service, illustrated in table 1, are defined in terms of the percentage of travel time spent delayed, such as travelling in platoons behind other vehicles. The percent of time delay was chosen as the measure of service for the 1985 HCM because it is more sensitive to variation in flow rate than other candidate measures, such as vehicle speeds (*12*). On steep grades, the average upgrade speed serves as an additional criterion to define the levels of service.

The operational effectiveness of passing lanes in the United States was previously evaluated based on field data by Harwood and St. John (*6*) and Harwood, St. John, and Warren (*13*). This field evaluation compared the quality of traffic operations (level of service) upstream and downstream of passing lanes. Field evaluations cannot compare the quality of traffic operations on a highway section with and without passing lanes, but comparisons of this type can be made with a computer simulation model. Therefore, simulation modeling of passing lanes was recently conducted with a computer model known as TWOPAS (*14*).

TWOPAS is a microcomputer simulation model of traffic operations on two-lane, two-way highways. TWOPAS is a

TABLE 1 LEVEL OF SERVICE CRITERIA FOR TWO-LANE HIGHWAYS

Level of Service	Percent Time Delay on General Segments	Average Upgrade Speed (mi/hr) on Specific Grades
A	≤ 30	≥ 55
B	≤ 45	≥ 50
C	≤ 60	≥ 45
D	≤ 75	≥ 40
E	> 75	≥ 25-40
F	100	< 25-40

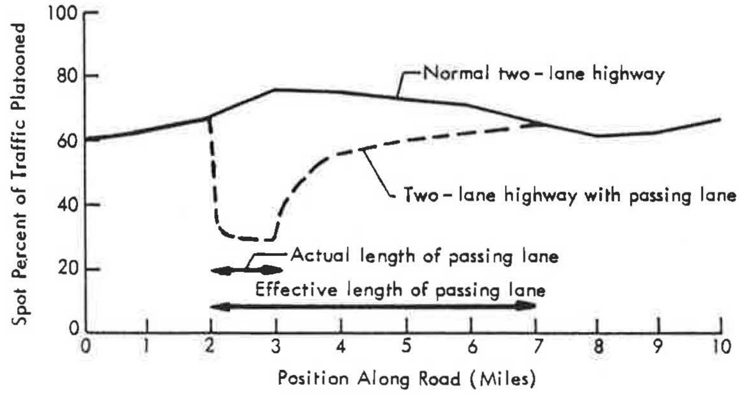

FIGURE 4 Example of the effect of a passing lane on two-lane highway traffic operations.

modified version of the TWOWAF model used in the development of Chapter 8 of the 1985 HCM. TWOPAS has the added capability to simulate the operational effects of passing and climbing lanes. The TWOWAF model was validated from field data for conventional two-lane highways by St. John and Kobett (*15*) and by Messer (*12*), and the added capability to simulate passing and climbing lanes was validated from field data by Harwood and St. John (*14*). The latter effort found good agreement between model results and field data for traffic platooning and traffic speeds upstream and downstream of passing lanes.

Figure 4 presents a conceptual illustration of the effect of a passing lane on traffic operations on a two-lane highway. The solid line in this figure shows the normal fluctuation of platooning on a two-lane highway with the availability of passing sight distance. When a passing lane is added, the percentage of vehicles following in platoons falls dramatically and stabilizes at about half the value for the two-lane road. Because platoons are broken up in the passing lane, its effective length extends for a considerable distance downstream of the passing lane. Thus, the installation of passing lanes on parts of a two-lane highway can improve traffic operations on the entire highway. The next section of the paper illustrates the determination of the effective length of passing lanes for different lengths and traffic flow rates, based on computer simulation results.

Effective Length of a Passing Lane Used for Analysis

Figure 5 illustrates the effects of passing lanes of various lengths on traffic platooning within a passing lane and downstream of a passing lane for flow rates of 400 and 700 vehicles per hour (vph) in one direction of travel. Figure 5 is based on the percentage of vehicles delayed in platoons at specific spot locations on the highway. It can be seen in figure 5 that the level of traffic platooning within a passing lane is less than half of the level observed upstream of the passing lane. Traffic platooning remains at a reduced level downstream of a passing lane. For a flow rate of 400 vph, the effects of passing lanes can still be substantial seven miles downstream of the beginning of the passing lane, especially for longer passing lanes. At the higher flow rate of 700 vph, nearly all of the operational benefits of the passing lane are gone within five miles, although there is a small residual effect even at seven miles downstream. The length of the passing lane has a strong influence on the improvement in traffic operations immediately downstream of the passing lane, but this differential between passing lane lengths largely disappears farther downstream.

The results in figure 5 indicate that the effective length of a passing lane can vary from three to eight miles, depending on passing lane length, traffic flow and composition, and downstream passing opportunities.

The concept of effective length is needed for analysis purposes to determine the overall effect of a passing lane on level of service over an extended highway section. For most cases, effective length can be estimated from figure 5, with adjustments for factors that might hasten or slow the downstream overtaking or catch-up process. If the two-lane highway downstream of the passing lane has few passing opportunities, for example, the effective length determined from figure 5 should be reduced.

In some cases, the effective length of a passing lane is constrained by other road features, such as small towns, four-lane sections, or additional passing lanes a few miles downstream. In these situations, the distance to the downstream constraint should be used as the effective length for analysis purposes, if this is less than that estimated from figure 5.

Effectiveness Over an Extended Road Section

Figure 6 illustrates the effectiveness of passing lanes of various lengths in improving traffic operations on two-lane highways, based on results obtained with the TWOPAS simulation model. The curves presented in figure 6, for passing lanes of varying lengths, represent their effectiveness in increasing traffic speeds and decreasing the percent of time vehicles spend delayed in platoons on a two-lane highway in moderately rolling terrain. The vehicle speed and platooning measures in figure 6 are averages over an eight-mile highway section with the passing lane located at the beginning; thus, these curves represent the combined effects of improved traffic operations in the passing lane and downstream of the passing lane. Figure 6 illustrates that passing lanes produce relatively small increases in vehicle speeds, but can dramatically decrease vehicle platooning.

An eight-mile highway section is used in figure 6 because

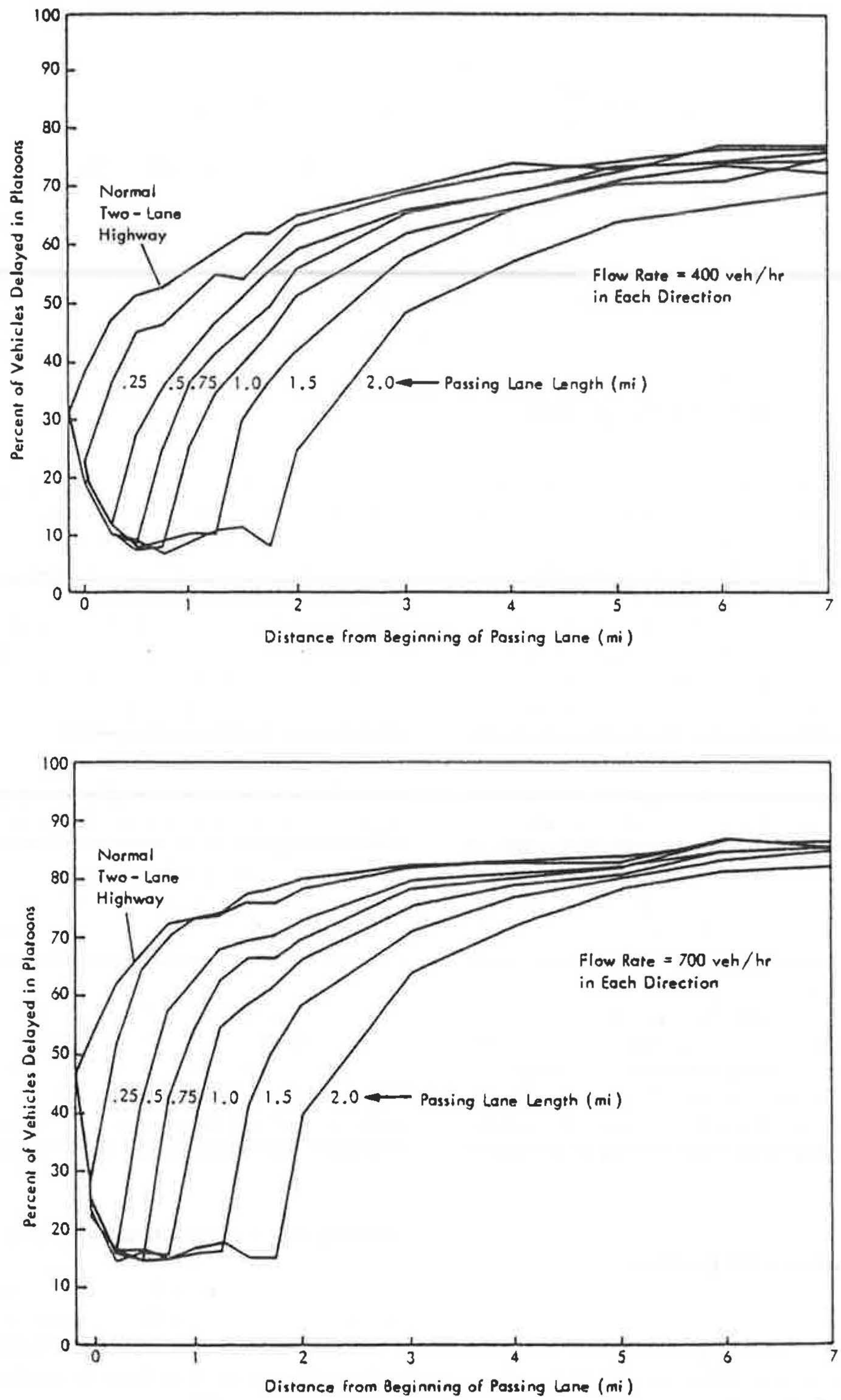

FIGURE 5 Gradual increase in percentage of vehicles delayed in platoons downstream of passing lanes.

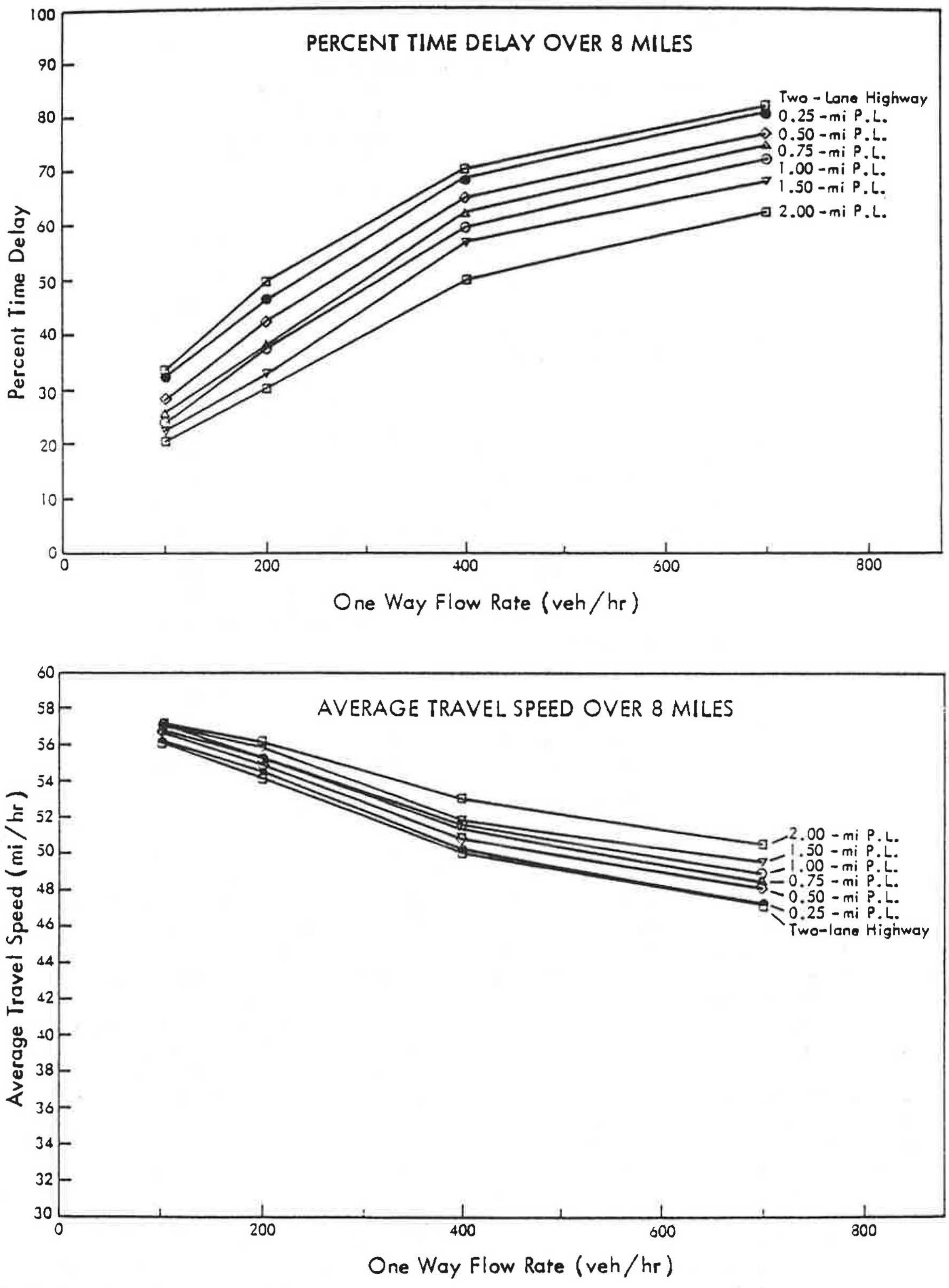

FIGURE 6 Computer simulation results for operational effectiveness of passing lanes.

TABLE 2 EFFECT OF PASSING LANES ON PERCENT TIME DELAY OVER AN EXTENDED ROAD LENGTH

Effective Length (mi)	PERCENT TIME DELAY — Passing Lane Length (mi) 0	0.25	0.50	0.75	1.00	1.50	2.00
One-way Flow Rate = 100 veh/hr							
3	33	30	20	17	17	17	17
5	33	31	25	22	19	17	17
8	33	32	28	26	24	22	20
One-way Flow Rate = 200 veh/hr							
3	50	39	29	25	25	25	25
5	50	44	37	31	29	25	25
8	50	46	42	38	37	33	30
One-wqy Flow Rate = 400 veh/hr							
3	70	67	57	49	43	35	35
5	70	68	62	57	54	49	38
8	70	69	65	62	60	57	50
One-way Flow Rate = 700 veh/hr							
3	82	79	69	63	55	45	41
5	82	80	74	71	66	60	52
8	82	81	77	75	72	68	63

the effective length of a passing lane includes both the passing lane itself and the downstream section of two-lane highway where platooning is lower than it would be without the passing lane. Table 2 presents the estimated reductions in percent time delay for three different effective lengths—3, 5, and 8 miles—as well as for different lengths of passing lane.

The selection of the design length of a passing lane is discussed in the following sections. Once the design length and the effective length used for analysis are determined, table 2 can be used to predict the percent time delay and, hence, the level of service on a highway section which includes a passing lane.

It should be noted that the base values of percent time delay for a normal two-lane highway in table 2 are higher than those specified in the HCM (see table 1) for ideal conditions. This is because the simulated results were derived for non-ideal conditions of terrain, no-passing zones, and traffic composition. Since these conditions can vary from one case to another, it is recommended that table 2 be entered using a given base value of percent time delay, rather than the traffic flow. In other words, the estimated two-lane highway percent time delay should be used to select the appropriate row of table 2, regardless of traffic flow. Linear interpolation in table 2 is acceptable.

Optimum Design Length for Passing Lanes

The optimum design length for a passing lane can be determined through a cost-effectiveness analysis. This can be illustrated by the data in table 3, which presents the percent time delay over an effective length of eight miles for passing lanes of various design lengths, the difference between the percent time delay for each design length and a conventional two-lane highway, and the ratio of this difference to the design length. This effectiveness ratio, the effectiveness in reducing vehicle platooning per unit length of passing lane, represents the relative cost-effectiveness of passing lanes, if one assumes that the cost of constructing a passing lane is proportional to its length. This assumption is reasonable for most situations, although the cost of constructing passing lanes can vary widely as a function of terrain. The passing lane lengths shown in table 3 were increased by 600 feet, half of the combined length

TABLE 3 REDUCTION IN PERCENT TIME DELAY PER UNIT LENGTH OF PASSING LANE

One-Way Flow Rate (veh/hr)	Passing Lane Length (mi) a/ 0.25	0.50	0.75	1.00	1.50	2.00
100	2.8	8.2	8.1	8.1	6.8	6.2
200	11.1	13.1	14.0	11.7	10.6	9.5
400	2.8	8.2	13.1	9.0	8.1	9.5
700	2.8	8.2	8.1	9.0	8.7	9.0

a/ Unit length of passing lanes increased by 600 ft to account for cost of constructing lane addition and lane drop tapers.

TABLE 4 OPTIMAL DESIGN LENGTHS FOR PASSING LANES

One-Way Flow Rate (veh/hr)	Optimal Passing Lane Length (mi)
100	0.50
200	0.50-0.75
400	0.75-1.00
700	1.00-2.00

of typical lane-addition and lane-drop tapers, in the computation of the effectiveness ratios to account for the cost of constructing these transition areas.

The optimum design lengths for passing lanes, based on the data in table 3, are tabulated in table 4. For flow rates of 200 vph or less in one direction of travel, the highest effectiveness per unit length is obtained for passing lanes with design lengths between 0.5 and 0.75 of a mile. Passing lanes shorter than 0.5 mile or longer than 0.75 mile are not as desirable at this flow rate because they provide less operational benefit per unit length. As flow rate increases above 200 vph, the optimum design length for a passing lane also increases. At a flow rate of 400 vph in one direction of travel, the optimum design length for a passing lane is 0.75 to 1.0 mile. At very high flow rates, such as 700 vph in one direction of travel, the optimum design length of passing lanes ranges from 1.0 to 2.0 miles. However, passing lanes longer than 1.0 mile may not be desirable, even for highways with peak flow rates of 700 vph in one direction of travel, because longer passing lanes would be suboptimal throughout the remainder of the day when traffic volumes are lower.

The effectiveness analysis indicates that short passing lanes are usually more effective per unit length and, therefore, per dollar spent on construction than long passing lanes. Thus, the overall level of service on a highway can often be improved more by constructing three 0.5-mile passing lanes spaced at intervals than by constructing one two-mile passing lane. The optimum design length for passing lanes on a specific section of two-lane highway could be based on the highest hourly flow rate that occurs frequently (for example, on a daily basis) on that specific highway section. The design hour volume, which occurs in only a few hours out of each year, may be too high to serve as the basis for the choice of a cost-effective passing lane length. It may be useful to evaluate traffic operations for several design hours, especially when the composition of traffic differs between weekdays and weekends.

SAFETY EFFECTIVENESS

Safety evaluations have shown that passing lanes and short four-lane sections reduce accident rates below the levels found on conventional two-lane highways.

Table 5 compares the results of two before-and-after evaluations of passing lane installation. These studies include accidents of all types for both directions of travel within the portion of the two-lane highway where the passing lanes were installed. A California study by Rinde (*16*) at 23 sites in level, rolling, and mountainous terrain found accident rate reductions due to passing lane installation of 11 to 27 percent, depending on road width. The accident rate reduction effectiveness at the 13 sites in level or rolling terrain was 42 percent. In data from 22 sites in four states, Harwood and St. John (*6*) found the accident rate reduction effectiveness of passing lanes to be 9 percent for all accidents and 17 percent for fatal and injury accidents. The combined data from both studies indicates that passing lane installation reduces accident rate by 25 percent. No difference was found between the accident rates of passing lanes of level and rolling terrain.

Harwood and St. John (*6*) found no indication in the accident data of any marked safety problem in either the lane-addition or lane-drop transition areas of passing lanes. In field studies of traffic conflicts and erratic maneuvers at the lane-drop transition areas of 10 passing lanes, lane-drop transition areas were found to operate smoothly. Overall, 1.3 percent of the vehicles passing through the lane-drop transition area created a traffic conflict, while erratic maneuver rates of 0.4 and 0.3 percent were observed for centerline and shoulder encroachments, respectively. The traffic conflict and

TABLE 5 ACCIDENT REDUCTION EFFECTIVENESS OF PASSING LANES

Source	Type of Terrain	Total Roadway Width (ft)[a]	No. of Passing Lane Sites	Percent Reduction: All Accidents	Percent Reduction: Fatal and Injury Accidents
Rinde[16]	Level, rolling, and mountainous	36	4	11	-
		40	14	25	-
		42-44	5	27	-
	Level and rolling sites only	36-44	13	42	-
Harwood and St. John[6]	Level and rolling	40-48	22	9	17
Combined Totals for Level and Rolling Terrain			35	25	-

[a] Total roadway width includes both traveled way and shoulders.

TABLE 6 RELATIVE ACCIDENT RATES FOR IMPROVEMENT ALTERNATIVES

Alternative	All Accidents	Fatal and Injury Accidents
Conventional two-lane highway	1.00	1.00
Passing lane section	0.75	0.70
Four-lane section	0.65	0.60

encroachment rates observed at lane-drop transition areas in passing lanes were much smaller than the rates found in lane-drop transition areas at other locations on the highway system, such as work zones.

An evaluation of cross-centerline accidents involving vehicles travelling in opposite directions on the highway found no safety differences between passing lanes with passing prohibited in the opposing direction and passing lanes with passing permitted in the opposing direction where adequate sight distance was available (*6*). The provision for passing by vehicles travelling in the opposing direction does not appear to lead to safety problems at the types of sites and flow rate levels (up to 400 vph in one direction of travel) where it has been permitted by the highway agencies that participated in the Harwood and St. John study. Both types of passing lanes had cross-centerline accident rates lower than those of comparable sections of conventional two-lane highway.

Reviewing a small number of climbing-lane sites in the United States, Jorgensen (*17*) found no change in accident experience. In the United Kingdom, Voorhees (*18*) found a 13 percent reduction in accidents where a climbing lane was provided.

A safety evaluation of nine short, four-lane sections in three states found a 34 percent lower total accident rate and a 43 percent lower fatal and injury accident rate on the short, four-lane sections than rates on comparable sections of conventional two-lane highways (*5*). These differences, although substantial, were not statistically significant because of the limited number of sites available. The cross-centerline accident rates for the short, four-lane sections were generally less than half the rates for the comparable two-lane sections.

Table 6 summarizes the relative accident rates found in recent research for passing lane sections and short, four-lane sections, expressed as ratios between the expected accident rate for each and the expected accident rate of a conventional two-lane highway.

SUMMARY

Passing lanes have been found to be effective in improving overall traffic operations on two-lane highways, and they provide a lower cost alternative to four-laning extended sections of highway. Passing opportunities on two-lane highways can be increased by the installation of passing lanes in level and rolling terrain, of climbing lanes on sustained grades, and of short sections of four-lane highway. The traffic operational effectiveness of passing lanes can be predicted as a function of flow rate, passing-lane length, and the percentage of traffic travelling in platoons, using the procedure presented above. The installation of a passing lane on a two-lane highway reduces accident rate by approximately 25 percent. Recommended geometric design, signing, and marking practices for passing lanes have also been developed. Further guidance on the use of passing lanes and other low-cost methods of improving traffic operations on two-lane highways (such as turnouts, shoulder driving sections, intersection turn lanes, and center two-way left-turn lanes) is provided by Harwood and Hoban (*5*).

ACKNOWLEDGMENTS

The work reported in this paper was conducted under sponsorship of the Federal Highway Administration. However, the findings and conclusions in the paper are those of the authors and do not necessarily represent the views of the Federal Highway Administration.

REFERENCES

1. J. Botha et al. *A Decision-Making Framework for the Evaluation of Climbing Lanes on Two-lane Two-way Rural Roads: Research Summary*. Report No. FHWA/CA/T0-80, University of California, California Department of Transportation, July 1980.
2. W. S. Homburger. *An Analysis of Safety at the Terminals of Climbing Lanes on Two-Lane Highways*. Report No. FHWA–CA–UCB–ITS–RR–86–3, University of California, Berkeley, May 1986.
3. C. J. Hoban and J. F. Morrall. *Overtaking Lane Practice in Canada and Australia*. Research Report No. ARR 144, Australian Road Research Board, 1985.
4. *Manual on Uniform Traffic Control Devices for Streets and Highways*, Federal Highway Administration, Washington, D.C., 1978 and subsequent revisions.
5. D. W. Harwood and C. J. Hoban. *Low-Cost Methods for Improving Traffic Operations on Two-Lane Highways—Informational Guide*. Report No. FHWA–IP–87–2, Federal Highway Administration, Washington, D.C., January 1987.
6. D. W. Harwood and A. D. St. John. *Passing Lanes and Other Operational Improvements on Two-lane Highways*. Report No. FHWA/RD–85/028, Federal Highway Administration, Washington, D.C., July 1984.
7. R. S. Hostetter and E. L. Seguin. The Effects of Sight Distance and Controlled Impedance on Passing Behavior. *Highway Research Board Bulletin 92*, HRB, National Research Council, Washington, D.C., 1965.
8. *Guide to Geometric Design of Rural Roads*. National Association of Australian State Road Authorities, Sydney, Australia, 1985.
9. *Design Procedure for Passing Lanes*. Ontario Ministry of Transportation and Communications, Downsview, Ontario, 1975.
10. A. Werner and J. F. Morrall. A Unified Traffic Flow Theory Model for Two-lane Rural Highways. *Transportation Forum*, Vol. 1, No. 3, 1985, pp. 79–87.
11. *Highway Capacity Manual*. Transportation Research Board

Special Report 209, TRB, National Research Council, Washington, D.C., 1985.
12. C. J. Messer. *NCHRP Project 3–28A Report: Two-Lane, Two-Way Rural Highway Capacity*. TRB, National Research Council, Washington, D.C., February 1983.
13. D. W. Harwood, A. D. St. John, and D. L. Warren. Operational and Safety Effectiveness of Passing Lanes on Two-Lane Highways. In *Transportation Research Record 1026*, TRB, National Research Council, Washington, D.C., 1985.
14. D. W. Harwood and A. D. St. John. *Operational Effectiveness of Passing Lanes on Two-lane Highways*. Report No. FHWA/RD – 86/196, Federal Highway Administration, Washington, D.C., 1986.
15. A. D. St. John and D. R. Kobett. *NCHRP Report 185: Grade Effects on Traffic Flow Stability and Capacity*. TRB, National Research Council, Washington, D.C., 1978.
16. E. A. Rinde. *Accident Rates vs. Shoulder Widths: Two-lane Roads, Two-lane Roads with Passing Lanes*. Report No. CA–DOT–TR–3147–1–77–01, California Department of Transportation, September 1977.
17. Roy Jorgensen and Associates. *Evaluation of Criteria for Safety Improvements on the Highway*. U.S. Department of Commerce, Bureau of Public Roads, 1966.
18. Martin Voorhees Associates. *Crawler Lane Study: An Economic Evaluation*. Department of the Environment, Great Britain, 1978.

Publication of this paper sponsored by Committee on Operational Effects of Geometrics.