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Passing Lane Effectiveness on Two-Lane Roads

Douglas W. Harwood
Midwest Research Institute
Kansas City, Missouri

INTRODUCTION

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 as much as 3 miles. Figure 1 illustrates a plan view of a typical passing lane section.

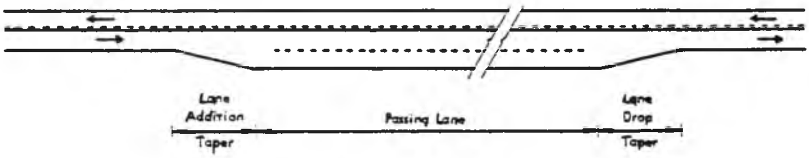

FIGURE 1. Plan View of Typical Passing Lane Section

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 the construction of 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:

1. To reduce delays at specific bottleneck locations, such as steep upgrades where slow-moving vehicles are present; and
2. 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 draw a clear traffic 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 the selection of an appropriate location is an important design decision.

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 developed minimum volume warrants for passing lanes based on average daily traffic volumes and percent of the highway length providing passing opportunities over the previous 2 to 6 miles.[1] Canadian research has developed a concept based on the percentage of highway length with ''assured'' passing opportunities to determine where passing lanes are needed.[2,3] Summaries of these results have also been presented by Hoban and Morrall[4] and 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).[6] These levels of service, illustrated in Table 1, are defined in terms of the percentage of travel time spent delayed, i.e., travelling in platoons behind other vehicles. The percent 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.[7] 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[8] and Harwood, St. John, and Warren.[9] 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

TABLE 1. Level of Service Criteria for Two-Lane Highways[6]

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

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,[10] which is a modified version of the TWOWAF model used in the development of Chapter 8 of the 1985 HCM.

Figure 2 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 flow rates based on computer simulation results.

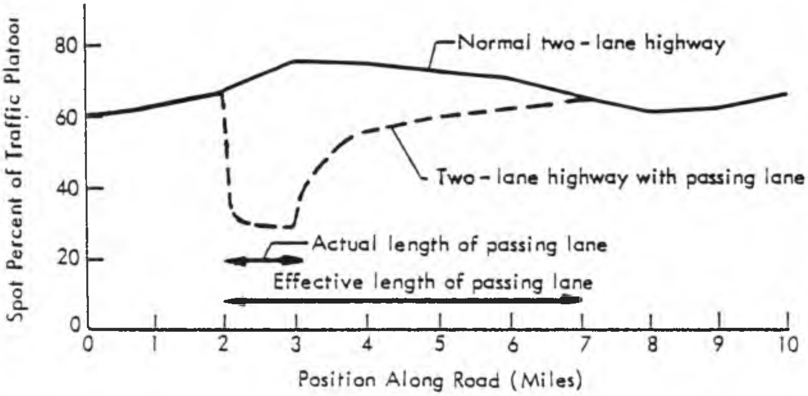

FIGURE 2. Example of the Effect of a Passing Lane on Two-Lane Highway Traffic Operations

EFFECTIVE LENGTH OF A PASSING LANE

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. The effective length of a passing lane can vary from 3 to 8 miles depending on passing lane length, traffic flow and composition, and downstream passing opportunities. The effective length of a passing lane will tend to be closer to 3 miles on highways with high flow rates, high truck percentages, relatively short passing lanes, and limited downstream passing opportunities.

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 from the beginning of the passing lane to the downstream constraint should be used as the effective length for analysis purposes, if this is less than the unconstrained estimate of effective length.

EFFECTIVENESS OVER AN EXTENDED ROAD SECTION

Figure 3 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 3, 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 3 are averages over an 8-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 3 illustrates that passing lanes produce relatively small increases in vehicle speeds, but can dramatically decrease vehicle platooning.

An 8-mile highway section is used in Figure 3 because 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 have been 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

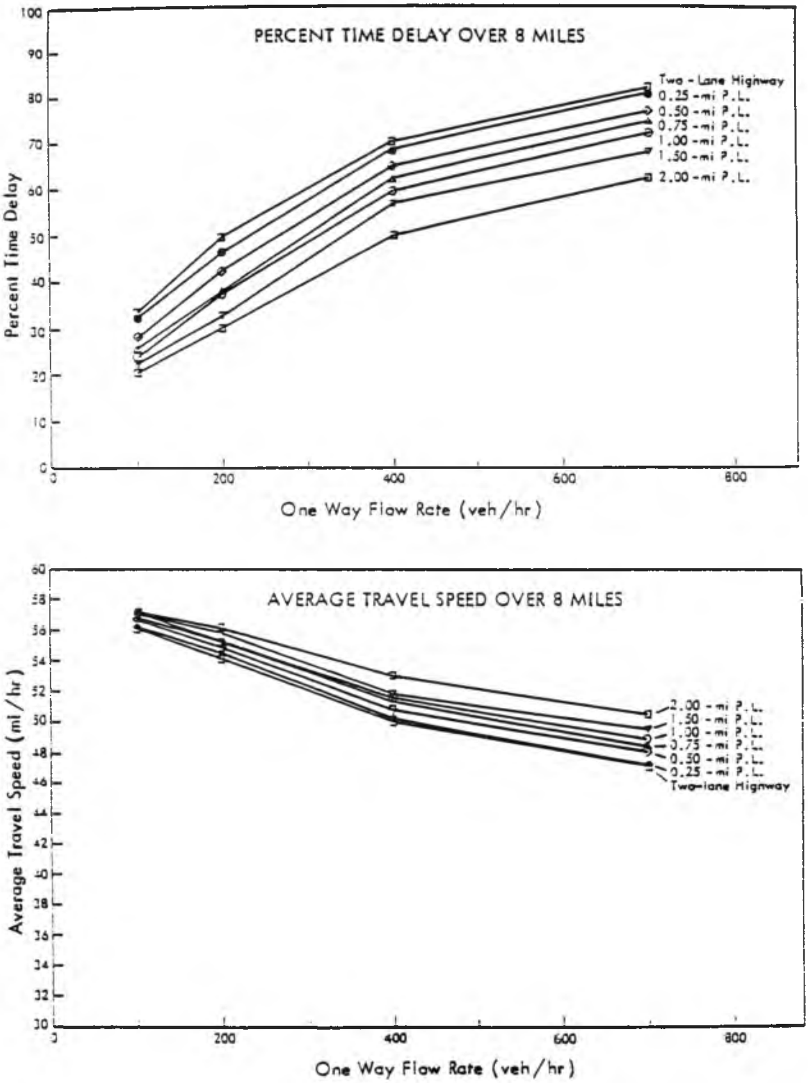

FIGURE 3. Computer Simulation Results for Operational Effectiveness of Passing Lanes[10]

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

TABLE 2. Effect of Passing Lanes on Percent Time Delay Over an Extended Road Length

	PERCENT TIME DELAY						
	Passing Lane Length (mi)						
Effective 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-way 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 appropriate row of Table 2, regardless of traffic flow. Linear interpolation in Table 2 is acceptable.

OPTIMAL DESIGN LENGTH FOR PASSING LANES

The optimal design length for a passing lane can be determined through a cost-effectiveness analysis. This can be illustrated by the cost-effectiveness data in Table 3. This table presents the percent time delay over an effective length of 8 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 ratio represents the effectiveness of passing lanes in reducing vehicle platooning per unit length. The use of design length in the denominator of the cost-effectiveness ratio represents the cost of constructing passing lanes, which can vary widely depending on terrain. The passing lane lengths shown in Table 3 were increased by

600 feet, half of the combined length of typical lane addition and lane drop tapers, in the cost-effectiveness computation to account for the cost of constructing these transition areas.

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.

The optimal design lengths for passing lanes, based on the data in Table 3, are tabulated in Table 4. For flow rates of 200 veh/hr or less in one direction of travel, the highest cost-effectiveness per unit length is obtained for passing lanes with design lengths between 0.5 and 0.75 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 veh/hr, the optimal design length for a passing lane also increases. At a flow rate of 400 veh/hr in one direction of travel, the optimal design length for a passing lane is 0.75 to 1.0 mile. At very high flow rates, such as 700 veh/hr in one direction of travel, the optimal design length of passing lanes ranges from 1.0 to 2.0 miles. However, the use of passing lanes longer than 1.0 mile in length may not be desirable, even for highways with peak flow rates of 700 veh/hr in one direction of travel, because longer passing lanes wold be suboptimal throughout the remainder of the day when traffic volumes are lower.

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

Cost-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 2-mile passing lane. The optimal 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 (e.g., 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 traffice 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-after evaluations of passing lane installation. A California study by Rinde[11] 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[8] 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.

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[11]	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[8]	Level and rolling	40-48	22	9	17
Combined Totals for Level and Rolling Terrain			35	25	—

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

Harwood and St. John[8] 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 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 in work zones.

An evaluation of cross-centerline accidents involving vehicles traveling 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 wehre adequate sight distance was available.[8] The provision for passing by vehicles traveling in the opposing direction does not appear to lead to any safety problems at the types of sites and flow rate levels (up to 400 veh/hr 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.

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.[8] 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.

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 traveling 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. Further guidance on the effective 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]

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