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Benefits and Design/Location Criteria for Passing Lanes

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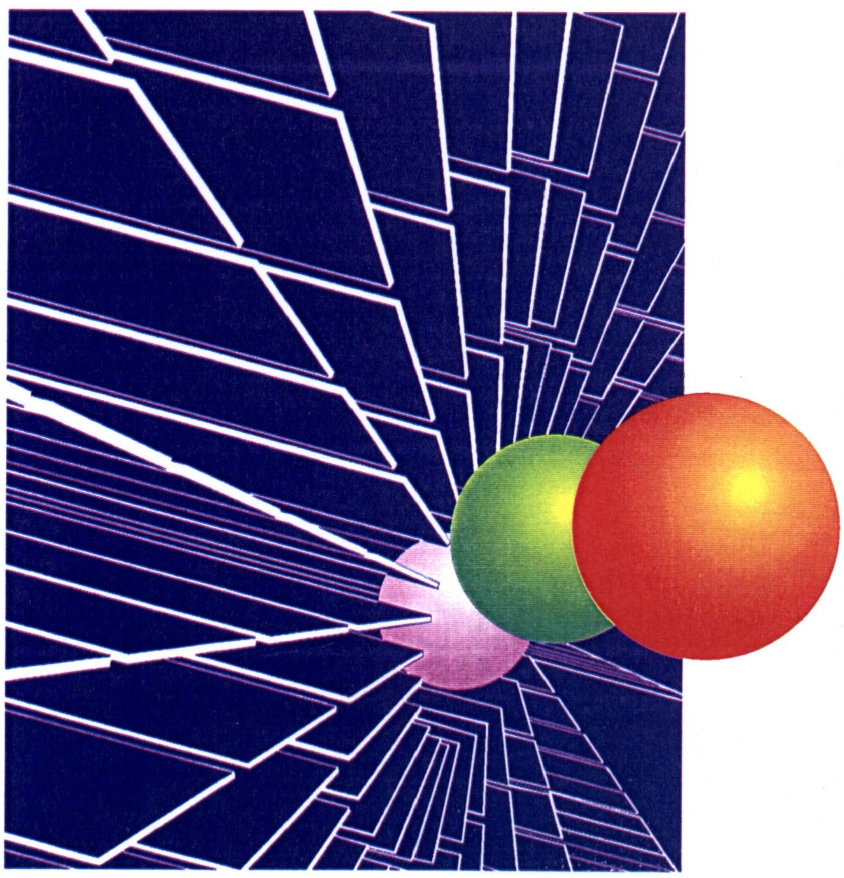

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16. Abstract

The objectives of this study are to demonstrate the feasibility and potential effectiveness of using passing lanes in Missouri, to evaluate the level of service and safety effects of existing passing lanes in Missouri, to establish criteria for determining where passing lanes could improve level of service and safety on Missouri highways, and to develop recommendations for the design, signing, and marking of passing lanes for potential application in Missouri. This report addresses the traffic operational and safety effectiveness of passing lanes as well as the geometric design and effective signing and marking of passing lanes. An evaluation of three existing passing lane sites on Missouri NHS routes found that those passing lanes improve percent time spent following on those roads by 10 to 31 percent in comparison to a conventional two-lane highway without passing lanes. A safety evaluation found that the accident frequency per mi per year within passing lane sections on two-lane highways is 12 to 24 percent lower than for conventional two-lane highway sections. Criteria to determine where passing lanes could provide level of service and safety benefits on Missouri highways are presented. Case studies of locations on five Missouri NHS routes examined the potential traffic operational and safety effectiveness of alternative passing lane configurations.

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Preface

This final report is submitted to the Missouri Department of Transportation (MoDOT) in accordance with the terms of the research contract MRI performed for MoDOT, entitled *Benefits and Design/Location Criteria for Passing Lanes*. This report was prepared by Ms. Ingrid B. Potts and Mr. Douglas W. Harwood, Midwest Research Institute.

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Executive Summary

Passing lanes have been used in many states to improve traffic operations on two-lane highways. The objectives of this study are to demonstrate the feasibility and potential effectiveness of using passing lanes in Missouri, to evaluate the level of service and safety effects of existing passing lanes in Missouri, to establish criteria for determining where passing lanes could improve level of service and safety on Missouri highways, and to develop recommendations for the design, signing, and marking of passing lanes for potential application in Missouri.

The objectives of using passing lanes on a two-lane highway are:

- To reduce delays at specific bottleneck locations, such as steep upgrades where slow-moving vehicles are present
- 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
- To improve safety by providing assured passing opportunities without the need for the passing driver to use the lane normally reserved for opposing traffic

The designer can choose from a number of alternative passing lane configurations, from an isolated passing lane to continuously alternating passing lanes. The choice of configuration, and the location of the added lanes, may vary with particular local needs and constraints. Location criteria for passing lanes are presented in Section 3 of this report.

Passing lanes can improve overall traffic operations on two-lane highways by breaking up traffic platoons and reducing delays caused by inadequate passing opportunities. One of the primary service measures used to define level of service for two-lane highways in the *Highway Capacity Manual* is "percent time spent following". Percent time spent following represents the freedom to maneuver and the comfort and convenient of travel. It is the average percentage of travel time that vehicles spend in platoons behind slow vehicles due to the inability to pass. When a passing lane is added, the percentage of vehicles following in platoons falls dramatically. The benefits of reduced percent time spent following extends for a considerable distance downstream of the passing lane.

Two-lane highways with passing lanes provide a definite improvement in level of service over two-lane highways without passing lanes. The improvement can be quite pronounced in that, at medium and high volumes, a roadway with continuously alternating passing lanes can provide an improvement by two levels of service over a conventional two-lane highway without passing lanes. A two-lane highway with less frequent passing lanes typically provides an improvement of one level of service over a conventional two-lane highway. The passing configuration selected should be appropriate to provide the desired level of service for the facility.

Geometric design of passing lanes should consider lane and shoulder widths, lane addition and lane drop taper designs, and intersection treatments. Recommendations related to each of these geometric design elements include:

- *Lane width*—The lane widths in a passing lane section should normally be the same as the lane widths on the adjacent sections of two-lane highway. On Missouri NHS routes, lanes widths of 12 ft should normally be used in passing lane sections.
- *Shoulder width*—The shoulder width in a passing lane section should not normally be narrower than the shoulder width on the adjacent two-lane highway. Shoulder widths of 10 ft should normally be used in passing lanes on Missouri NHS routes, although narrower shoulders can be used where this would substantially reduce costs.
- *Lane addition taper*—The length of the lane addition transition area at the upstream end of a passing lane should be half to two-thirds of the length of the MUTCD lane drop taper for the appropriate off-peak 85th percentile speed.
- *Lane drop taper*—The length of the lane drop transition taper at the downstream end of a passing lane should be determined from the MUTCD taper formula as a function of off-peak 85th percentile speed. A wide shoulder is desirable at the lane drop taper to provide a recovery area should drivers encounter a merging conflict.
- *Intersection treatments*—The locations of major intersections and high-volume driveways should be considered in selecting passing lane locations, to minimize the volume of turning movements on road sections where passing is encouraged. Where major intersections or high-volume driveways are present in a passing lane, provision of left-turn lanes should be considered.

The signing and marking of passing lanes is partially addressed in the MUTCD, which indicates the appropriate centerline markings for passing lanes and the signing and marking of lane drop transition areas. Recommendations related to the signing and marking of passing lanes include:

- Advance signing for passing lanes is desirable approximately 0.5 mi upstream of each passing lane. A second advance sign approximately 2 mi upstream of each passing lane is also desirable. A regulatory sign that reads KEEP RIGHT EXCEPT TO PASS should be placed at the beginning of the lane drop taper for each passing lane. Signing in advance of the lane drop of each passing lane should include lane reduction symbol transition sign (MUTCD W4-2) approximately 1,000 ft upstream of the lane drop taper and a text sign RIGHT LANE ENDS (W9-1) or LANE ENDS MERGE LEFT (W9-2) approximately 500 ft upstream of the lane drop taper.

- Pavement markings for passing lanes should be marked in accordance with MUTCD Figure 3B-3. MoDOT's normal practice is to mark the opposing direction to a passing lane to permit passing where sight distance exceeds the MUTCD passing sight distance criteria. There is no general agreement among state highway agencies on the value of lane addition transition markings. Lane drop transition markings at the downstream end of a passing lane should be provided in accordance with MUTCD Figure 3B-12.

An evaluation of three existing passing lane sites on Missouri NHS routes found that those passing lanes improve percent time spent following on those roads by 10 to 31 percent in comparison to a conventional two-lane highway without passing lanes. At one site, the traffic operational level of service was LOS B both with and without the passing lanes, but the level of service was nearly LOS A with passing lanes and nearly LOS C without passing lanes. At a second site, the level of service was LOS B with passing lanes, but would have been LOS D without passing lanes. At a third site, the level of service was LOS A with passing lanes, but would have been LOS C without passing lanes.

A safety evaluation found that the accident frequency per mi per year within passing lane sections on two-lane highways is 12 to 24 percent lower than for conventional two-lane highway sections and that the percent difference in accident frequency between roadways with and without passing lanes increases with increasing traffic volume. Safety prediction models for conventional two-lane highways, two-lane highways with passing lanes, and four-lane highways were developed in the research; these models allow safety predictions to be made for any traffic volume level.

Two types of criteria were developed for selecting passing lane locations in Missouri. *Screening criteria* can be used to screen an entire network of two-lane highways for potential candidates for passing lanes. *Site-specific investigation criteria* can be used to identify specific roadway sections where passing lanes may provide substantial level of service and safety benefits and that warrant further investigation in the field.

Case studies were conducted at sites on five Missouri NHS routes that met the recommended selection criteria to estimate the potential traffic operational and safety benefits of providing passing lanes on existing two-lane highways and to illustrate how the process of selecting passing lanes locations can be incorporated in the project development process.

At three of the five case study sites, the maximum passing lane configuration would improve traffic operations for the years 2003 and 2023 by two levels of service (i.e., from LOS D to B or from LOS C to A). At the other two case study sites, the maximum passing lane configuration would improve traffic operations in years 2003 and 2023 by one level of service (i.e., LOS C to B).

Results of the traffic operational evaluation of the five case study sites are summarized below.

Location[a]	Level of service for specific design alternatives			
	Existing configuration[b]	Intermediate passing lane configuration	Maximum passing lane configuration	Four-lane divided highway
CURRENT TRAFFIC VOLUMES				
US 54, Andrain Co.	B/C[c]	B[d]	A	A
MO 13, Lafayette/Johnson Cos.	C	B	A	A
MO 37, Barry Co.	C	–	B	A
MO 5, Laclede Co.	C	B	A	A
US 67, Wayne Co.	B/C[c]	A	A	A
PROJECTED TRAFFIC VOLUMES FOR YEAR 2023				
US 54, Andrain Co.	C	B	B[d]	A
MO 13, Lafayette/Johnson Cos.	D	C	B	A
MO 37, Barry Co.	C	–	B	A
MO 5, Laclede Co.	C	B	A	A
US 67, Wayne Co.	C	A	A	A

[a] Specific locations of the case study sections on these routes are identified in Section 11 of the report.
[b] The existing configuration is a two-lane highway with no passing lanes.
[c] Level of service B or C, depending on the directional split of traffic.
[d] Level of service B, but very close to level of service A.

The case studies found that intermediate passing lane configurations would reduce total accident frequency by 3 to 8 percent; the maximum passing lane configuration would reduce total accident frequency by 6 to 12 percent.

Section 1. Introduction

The National Highway System (NHS) is the backbone of Missouri's rural road network. The NHS includes the roads that are the most important links for moving people and goods in all parts of the state. The NHS includes the Interstate highway system, as well as an extensive network of nonfreeway facilities operated by the Missouri Department of Transportation (MoDOT).

The rural NHS system in Missouri includes 3,370 mi of highways, including 800 mi of freeway and 2,570 mi of nonfreeway facilities. The Interstate highway system consists of freeways that were designed to the highest geometric standards and have no direct access except at interchanges. The nonfreeway facilities consist of highways that have at-grade intersections and driveways. Table 1 shows that the nonfreeways facilities on the rural NHS system include 36 percent four-lane divided highways, 3 percent four-lane undivided highways, and 61 percent two-lane highways. Thus, a good share of the rural NHS system consist of four-lane divided highway that operate with a high level of service and safety. However, the majority of the nonfreeway portion of the NHS in Missouri is composed of two-lane highways, all but a few of which serve average annual daily traffic volumes less than 20,000 veh/day.

Table 1. Rural NHS Roadway Mileage in Missouri

Highway type	Total length (mi)	Percentage of total length
Four-lane divided	919.7	35.8
Four-lane undivided	67.9	2.6
Two-lane undivided	1,582.7	61.6
	2,570.3	

NOTE: Preliminary estimates.

For any given traffic volume level, a conventional two-lane highway is inherently more congested than a four-lane highway and will operate at a lower level of service than a four-lane highway. Two-lane highways provide lower level of service than four-lane highways for several reasons. First, a two-lane highway has only half as many through travel lanes as a four-lane highway. Second, drivers that encounter slower vehicles on a two-lane highway must pass using the lane normally reserved for opposing traffic. Thus, drivers on a two-lane highway can pass only where there is adequate sight distance to see opposing traffic and only when no opposing traffic is present. Because of these limitations, the capacity for one direction of travel on a two-lane highway under the best conditions is 1,700 pc/h, while the capacity for one direction of travel on a four-lane divided nonfreeway under the best conditions is 4,400 pc/h.(1)

MoDOT has an ongoing program of reconstructing two-lane highways on the rural NHS system as four-lane divided highways. However, given funding constraints, it may be many years before all two-lane highways with low levels of service can be widened to four lanes. In many cases, improved operations and safety can be obtained on two-lane highways, at substantially less cost than widening to four lanes, through the use of passing lanes. Passing lanes improve the traffic operational level of service on a two-lane highway because they increase passing opportunities for motorists who are delayed behind slower vehicles. For this reason, passing lanes are quite popular with motorists. Passing lanes provide an intermediate level of service between that provided by a conventional two-lane highway and that provided by a four-lane highway. Furthermore, passing lanes have the added advantage of improving safety on the highways where they are provided.

For some NHS routes, a two-lane highway with passing lanes may be appropriate as the ultimate design that can serve anticipated traffic volumes at a good level of service for many decades to come. For other NHS routes, the addition of passing lanes may put off the need for an expensive four-laning project by providing a satisfactory level of service for 10 to 20 years. Still other NHS routes may have an immediate need for four-laning; however, if funds for four-laning are not available, the addition of passing lanes might be considered as an interim measure.

For example, under the best conditions, a two-lane highway without passing lanes can serve traffic at level-of-service C for two-way design volumes up to approximately 1,100 pc/hr. Under the best design conditions, a two-lane highway with minimal passing lane frequency can serve two-way design volumes up to approximately 1,370 pc/hr at level-of-service C, while a two-lane highway with intermediate passing lane frequency can serve two-way design volumes up to approximately 1,790 pc/hr at level-of-service C. A two-lane highway with continuously alternating passing lanes can serve two-way design volumes up to approximately 2,800 pc/hr at level-of-service C so long as the capacity for one direction of travel on a two-lane highway—a one-way volume of 1,700 pc/hr—is not exceeded.

By contrast, a four-lane divided highway under the best conditions can operate at level-of-service C at volumes up to approximately 6,000 pc/hr. However, for many NHS routes, the four-lane divided highway may provide substantial excess capacity for which there is not an immediate need.

Passing lanes have been used in many states to improve traffic operations on two-lane highways. States that use passing lanes include Arkansas, California, Kansas, Kentucky, Michigan, Minnesota, Montana, Nevada, Oklahoma, Oregon, Utah, Washington, and Wisconsin.

The objectives of this study are to demonstrate the feasibility and potential effectiveness of using passing lanes in Missouri, to evaluate the level of service and safety effects of existing passing lanes in Missouri, to establish criteria for determining where passing lanes could improve level of service and safety on Missouri highways, and to develop recommendations for the design, signing, and marking of passing lanes for potential application in Missouri.

The remainder of this report is organized as follows. Section 2 presents an overview of passing lanes and their uses. Section 3 addresses current location criteria for passing lanes. Section 4 discusses the traffic operational effectiveness, and Section 5, the safety effectiveness of passing lanes. Geometric design issues related to passing lanes are addressed in Section 6. Section 7 discusses effective signing and marking of passing lanes. Sections 8 and 9 present the results of traffic operational and safety analysis of existing passing lanes in Missouri. Section 10 presents criteria for selecting passing lane locations. Results of the case studies are presented in Section 11. Finally, Section 12 presents the conclusions and recommendations of the research.

Section 2.
Passing Lane Overview

Definition of Passing Lanes

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 ft to as much as 3 mi. Figure 1 illustrates a plan view of a typical passing lane section. Figure 2 presents a photograph of a typical passing lane.

Throughout this report, the term passing lane is used broadly to refer to all types of added lanes that improve passing opportunities over a defined length of a highway that normally has two travel lanes. A three-lane cross section (with an added lane in one direction of travel) and a short section of four-lane roadway (with added lanes in both directions of travel) are both considered to be passing lanes. A climbing lane on a steep upgrade is another form of passing lane. Where the text specifically addresses passing lanes at locations other than on steep grades, it will refer to passing lanes in level and rolling terrain.

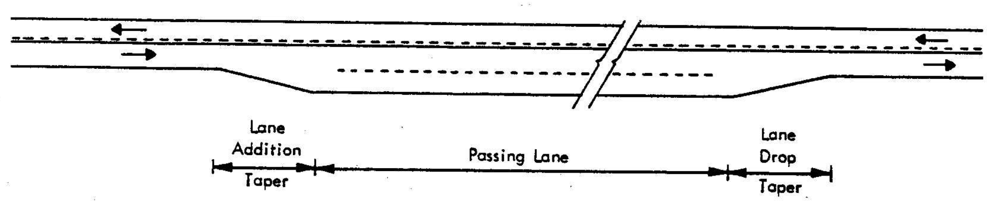


Figure 1. Plan View of Typical Passing Lane Section

Figure 2. Typical Passing Lane Used on Two-Lane Highways

Objectives of Using Passing Lanes

The objectives of using passing lanes on a two-lane highway are:

- to reduce delays at specific bottleneck locations, such as steep upgrades where slow-moving vehicles are present
- 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
- to improve safety by providing assured passing opportunities without the need for the passing driver to use the lane normally reserved for opposing traffic

The first objective, to reduce delays at bottleneck locations, has been recognized for some time; for example, the provision of climbing lanes for trucks on steep upgrades serves this function.

The second objective, to improve overall traffic operations, has evolved more recently, particularly as a result of the lack of funds for major road improvements. Highway agencies have found that added lanes in level and rolling terrain can be as effective as climbing lanes on grades in improving two-lane highway traffic operations. In practice, many passing lanes perform both of these 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 mi. Furthermore, the location of the passing improvement can be varied and the selection of an appropriate location is an important design decision.

The third objective of a passing lane is to improve safety on a two-lane highway. A portion of the safety benefit of providing a four-lane highway can be obtained through the addition of passing lanes.

Passing Lane Configurations

When passing lanes are provided to improve overall traffic operations over a length of road, they are often constructed systematically at regular intervals. The designer can choose from a number of alternative configurations,[2, 3] as illustrated in Figure 3. The choice of configuration, and the location of the added lanes, may vary with particular local needs and constraints, so there is no single correct answer. Table 2 presents the typical applications for each of the alternative configurations.

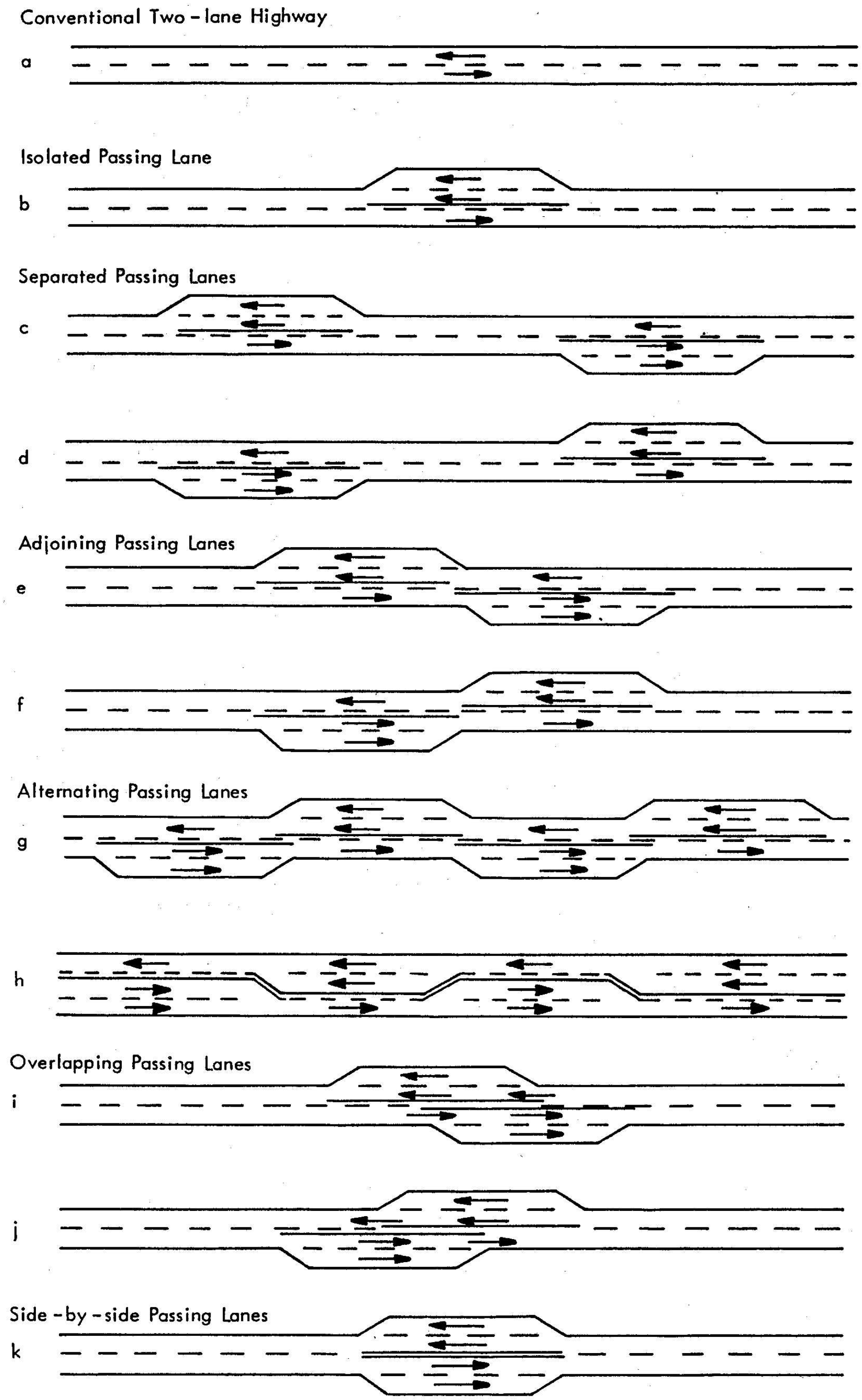


Figure 3. Alternative Configurations for Passing Lanes[2, 3]

Table 2. Typical Applications for Each Alternative Configuration

Configuration	Typical applications
Conventional two-lane highway (Configuration a)	• Two-lane highway with sufficient level of service for which passing lanes are not needed • Two-lane highway where a climbing lane is not warranted
Isolated passing lane (Configuration b)	• Two-lane highway with passing lane provided at a spot location to dissipate queues • Two-lane highway with climbing lane provided on a grade, where warranted, to allow motorists to pass slower vehicles
Separated passing lanes (Configurations c and d)	• Often used in pairs, one in each direction of travel, at regular intervals along a two-lane highway • Frequency of passing lanes depends on desired level of service • Configuration d is often appropriate where a city or town is located at either end of a roadway section
Adjoining passing lanes (Configuration e, "tail-to-tail")	• Often used in pairs, one in each direction of travel, at regular intervals along a two-lane highway • Frequency of passing lanes depends on desired level of service • Has the advantage of building platoons before the passing lane • Has the advantage of providing lane drop areas of opposing passing lanes that are not located adjacent to one other • Buffer area between passing lanes in opposing directions is typically 500 ft or more
Adjoining passing lanes (Configuration f, "head-to-head")	• Often used in pairs, one in each direction of travel, at regular intervals along a two-lane highway • Buffer area between passing lanes in opposing directions is typically 1,500 ft or more • Where a buffer of sufficient length cannot be provided or where longer passing lanes are needed to achieve the desired level of service, overlapping passing lanes may be considered (see discussion of configurations i and j below)
Alternating passing lanes (Configurations g and h)	• Appropriate for two-lane roadways carrying relatively high traffic volumes where nearly continuous passing lanes are needed to achieve the desired level of service • Particularly appropriate over an extended section of roadway where a wide pavement is already available • May use either a two-lane cross section with added pavement for passing lanes (Configuration g) or a three-lane cross section with the middle lane used for alternating passing lanes (Configuration h)

Table 2. Typical Applications for Each Alternative Configuration (Continued)

Configuration	Typical applications
Overlapping passing lanes (Configurations i and j)	• Often used at crests where a climbing lane is provided on each upgrade; climbing lanes are overlapped so that the lane drop for each climbing lane is on the downgrade • May be used where space is too limited (e.g., between major intersection, bridges, etc) to provide two adjoining passing lanes with a buffer
Side-by-side passing lanes (Configuration k)	• Appropriate where sufficient length for adjoining passing lanes is not available • Particularly appropriate where this is the ultimate design for the highway

Additional factors to consider in choosing an appropriate configuration for passing lanes include:

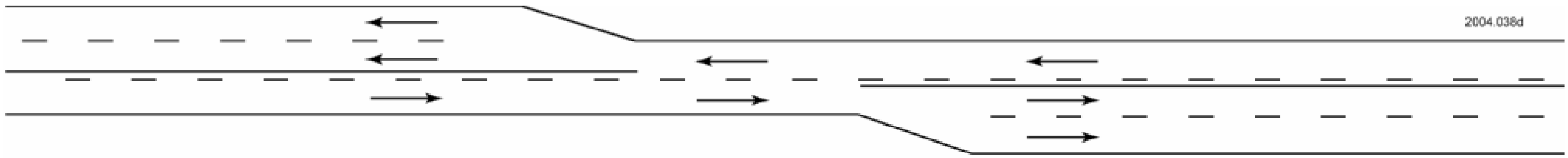
- Construction of a short four-lane section at the least expensive location can provide a substantial proportion of the benefits of the ultimate design for a relatively small proportion of the total cost, particularly if major bridge work or right-of-way acquisition can be avoided. This staged four-laning will generally return a high marginal benefit-cost ratio, while the 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.
- 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. The length of the buffer area between adjoining passing lanes depends on whether the configuration is "tail-to-tail" (Configuration e) or "head-to-head" (Configuration f). Figure 4 illustrates the relative buffer length that is appropriate for each configuration. For a pair of "tail-to-tail" passing lanes, the buffer area is typically 500 ft or more, but the adjoining passing lanes *may* be located immediately adjacent to one another. For a pair of "head-to-head" passing lanes, the buffer area may be between 1,000 and 1,500 ft.

Cost of Constructing Passing Lanes

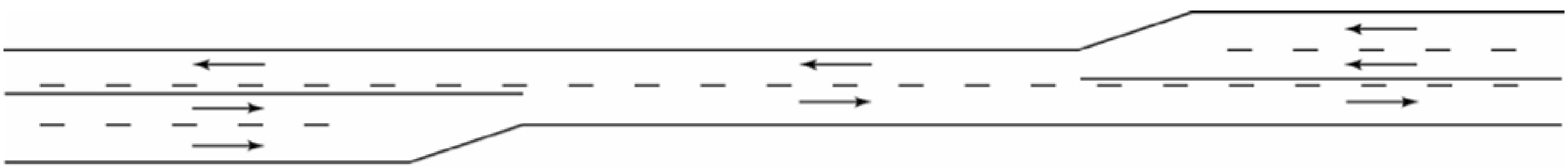
A key advantage of providing passing lanes on two-lane highways is that they are usually substantially less expensive to construct than other design alternatives, such as a four-lane divided highway. The estimated costs of adding a passing lane to an existing two-lane highway or constructing a four-lane divided highway are as follows:

- Add passing lane in one direction of travel on existing two-lane highway — $534,000/mi
- Add passing lanes in both directions of travel on existing two-lane highway (e.g., overlapping passing lanes) — $1,068,000/mi
- Convert existing two-lane highway to four-lane divided highway — $1,748,000/mi

These estimates include costs for grading and drainage, base and surface pavement courses, right of way, and contingencies. In comparing the cost estimates presented above, it should be noted that the cost of constructing a four-lane divided highway is incurred over the entire length of the project, while the costs of passing lane alternatives are normally incurred over only a portion of the project.



a) “Tail-to-tail” (Configuration e)



b) “Head-to-head” (Configuration f)

Figure 4. Relative Buffer Length for “Tail-to-Tail” and “Head-to-Head” Passing Lane Configurations

Section 3.
Location Criteria for Passing Lanes

When passing lanes are provided at an isolated location, their objective 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 operational 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. Design for sight distance and taper lengths further defines the location of such lanes. Existing warrants and location criteria for passing lanes are presented below.

When passing lanes are provided to improve overall traffic operations over a length of road, there is much more flexibility in the choice of passing lane locations to maximize their operational effectiveness and minimize construction costs. Location guidelines for passing lanes are summarized below.

The remainder of this section summarizes existing warrants, criteria, and guidelines for locating passing and climbing lanes. Criteria for selecting passing lane locations in Missouri are presented in Section 10 of this report.

Location Guidelines for Passing Lanes

- A primary objective in choosing the location for a passing lane should be to minimize construction costs, subject to other constraints. The cost of constructing a passing lane can vary substantially, depending on terrain, highway structures, and adjacent development. Thus, the choice of a suitable location for a passing lane may be critical to its cost-effectiveness. While the location of a climbing lane may be dictated by the location of the upgrade, passing lanes in level and rolling terrain can often be placed where they are least expensive to construct, avoiding locations with high cuts and fills and existing structures that would be expensive to widen.
- The passing lane location should appear logical to the driver. The value of passing lanes is more obvious to the driver at locations where passing sight distance is restricted than on long tangent sections which 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 should be avoided, since they may not be suitable for passing.
- The passing lane location may be on a sustained grade or on a relatively level section. If delay problems on the grade are severe, the grade will usually be the preferred location for a passing lane, which will then generally be referred to as a climbing lane. However, if platooning delays exist for some distance along a

road, locations other than upgrades should also be considered. While speed differences are often greater on upgrades, particularly if heavily loaded trucks are present, construction costs and constraints may be greater at such locations. Some types of slow vehicles are not slowed by upgrades as dramatically as heavy trucks, so passing lanes in rolling terrain may provide opportunities to pass such vehicles that are just as good as on upgrades. Passing lanes are also effective in level terrain where the demand for passing opportunities exceeds supply.

- The choice of passing lane location should take into account the need for adequate sight distance at the lane addition and lane drop tapers. This is discussed further in Section 6.
- 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, such as exclusive left-turn lanes, should be considered. The prohibition of passing by vehicles traveling in the opposing direction should also be considered on passing lane sections with higher-volume intersections and driveways.
- 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 a realignment of a road segment with safety problems.

Location Guidelines for Climbing Lanes

The AASHTO *Green Book*[4] considers a climbing lane on a two-lane highway upgrade to be economically justified when the following criteria are met.

1. Upgrade traffic flow rate in excess of 200 veh/h
2. Upgrade truck flow rate in excess of 20 veh/h
3. One of the following conditions exist:
    - a 10-mph or greater speed reduction is expected for a typical truck
    - level-of-service E or F exists on the grade
    - a reduction of two or more levels of service is experienced when moving from the approach segment to the grade

The economic criteria indicate that a climbing lane may be provided when the criteria are met, not that a climbing lane must be provided.

Green Book Exhibit 3-63 shows the critical length of grade that will result in various speed reductions for a truck with an assumed weight-to-power ratio of 200 lb/hp and an initial speed of 70 mph for grades up to 9 percent. The *Green Book* exhibit is a useful tool in assessing the need for climbing lanes if the assumptions on which it is based are met. In NCHRP Report 505, *Review of Truck Characteristics as Factors in Roadway Design*,[5] MRI has developed a spreadsheet that can be used to determine the speed profile for a truck of any specified weight-to-power ratio, with any specified initial speed, on an upgrade with any specified vertical profile (not just a constant percent grade). This spreadsheet will provide a more flexible tool for evaluating the need for climbing lanes.

As noted above, climbing lanes may also be justified, even where the critical length of grade is not exceeded, based on level-of-service analyses conducted with HCM procedures.

Section 4. Traffic Operational Effectiveness of Passing Lanes

This section addresses the traffic operational effectiveness of passing lanes. The section first introduces the fundamental concepts of two-lane highway traffic operations, including the effect of passing supply and demand on traffic platooning and the assessment of level of service and capacity using the procedures of the *Highway Capacity Manual*.[1] Specific estimates of the traffic operational effects of passing lanes are then presented.

Passing Demand and Supply

The need for passing opportunities on a two-lane road arises when the demand for passing opportunities exceeds their supply. It should be noted that the demand for passing opportunities can vary considerably with the mix of traffic characteristics on a road. The supply of passing opportunities on a two-lane road depends on the availability of passing sight distance and gaps in the opposing traffic stream. It is common to characterize passing supply by the percentage of the road length where passing is permitted and by the percentage of road length with passing sight distance greater than a specified value. Criteria for marking no-passing zones on two-lane highways are set by the *Manual on Uniform Traffic Control Devices for Streets and Highways*[6] (MUTCD). For 60-mph roadways, a no-passing zone is warranted where the passing sight distance falls below 1,000 ft. This requirement assures that passing is prohibited where sight distance is inadequate and passing would be unsafe. However, passing zones as short as 400 ft can occur between no-passing zones, and such short zones do not provide effective opportunities to pass other than very slow-moving vehicles. Engineers should be aware that some roads may appear to provide a high percentage of length in passing zones, but in practice allow few passing opportunities and experience high levels of platooning. The lack of passing opportunities may be further increased by high traffic volume levels that limit the frequency of adequate gaps in opposing traffic.

Traffic platoons develop and grow as faster vehicles catch up with slower ones and are unable to pass. The percentage of traffic following in platoons reflects the extent to which passing demand exceeds supply, and hence the extent of delay to drivers caused by inadequate passing opportunities. The percentage of their travel time that drivers spend following other vehicles is one of the measures of effectiveness used by the 2000 *Highway Capacity Manual*[1] (HCM) to define the level of service on two-lane highways.

HCM Level of Service Procedures

The HCM uses level of service (LOS) to characterize the quality of service provided by a highway facility in terms of operational measures related to speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience. The level of service for a two-lane highway is defined in terms of two primary service measures:

- percent time spent following
- average travel speed

Percent time spent following represents the freedom to maneuver and the comfort and convenience of travel. It is the average percentage of travel time that vehicles spend in platoons behind slow vehicles due to the inability to pass. Percent time spent following is difficult to measure in the field. However, the percentage of vehicles traveling at headways of less than 3 sec at a representative location can be used as a surrogate measure.

Average travel speed represents the mobility on a two-lane highway; it is the length of the highway segment divided by the average travel time of all vehicles traversing the segment during a designated interval of time.

The HCM defines the level of service for two classes of two-lane highways:

- Class I—These are two-lane highways on which motorists expect to travel at relatively high speeds. Two-lane highways that are major intercity routes, primary arterials connecting major traffic generators, daily commuter routes, or primary links in state and national highway networks generally are assigned to Class I. Class I facilities most often serve long-distance trips or provide connecting links between facilities that serve long-distance trips.
- Class II—These are two-lane highways on which motorists do not necessarily expect to travel at high speeds. Two-lane highways that function as access routes to Class I facilities, serve as scenic or recreational routes that are not primary arterials, or pass through rugged terrain are generally assigned to Class II. Class II facilities most often serve relatively short trips, the beginning and ending portion of longer trips, or trips for which sightseeing plays a significant role.

NHS routes are, essentially by definition, Class I highways. Because efficient mobility is of paramount importance on such highways, both percent time spent following and average travel time are used to define level of service. The level-of-service criteria for Class I highways are presented in Table 3. On high-speed roadways, level of service is defined primarily by percent time spent following. However, roadway alignments with reduced design speeds will limit the level of service that can be achieved.

Table 3. Level of Service Criteria for Two-Lane Highways in Class I[1]

LOS	Percent time spent following	Average travel speed (mph)
A	≤ 35	> 56
B	> 35-50	> 50-56
C	> 50-65	> 43-50
D	> 65-80	> 37-43
E	> 80	≤ 37

Note: LOS F applies whenever the flow rate exceeds the segment capacity.

HCM Chapter 20 presents specific procedures for determining the percent time spent following, average travel speed, and level of service for specific two-lane highway segments, including two-way segments and directional segments. The roadway section characteristics considered in determining level of service for a two-lane highway include:

- two-way volume during peak hour (veh/h)
- peak hour factor
- directional split
- percent trucks
- percent recreational vehicles
- terrain
- percent no-passing zones
- free-flow speed
- lane width
- shoulder width
- access point density

Traffic Operations in Passing Lanes

The effect of a passing lane on traffic operations on a two-lane road is illustrated by Figure 5. The solid line in this figure shows the normal fluctuation of spot platooning on a two-lane highway with the availability of passing sight distance and passing opportunities. Spot platooning is a surrogate for percent time spent following, a key factor in determining level of service. When a passing lane is added, the percentage of vehicles following in platoons falls dramatically and stabilizes at slightly less than 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. The HCM shows that percent time spent following will be reduced for 4 to 13 mi downstream of a passing lane, depending on traffic volume. Thus, passing lanes can improve level of service not only within the length of the passing lane itself but also downstream of the passing lane.

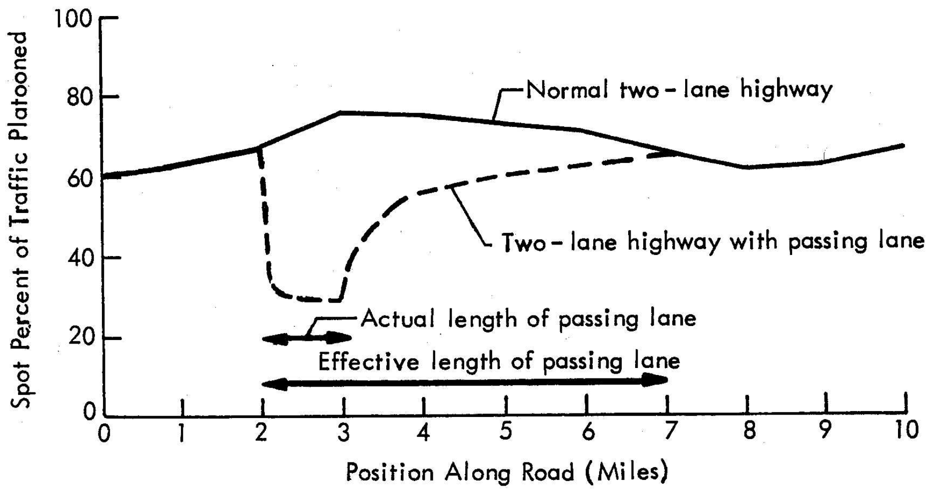


Figure 5. Example of the Effect of a Passing Lane on Two-Lane Highway Traffic Operations

Passing lanes have been found to increase average travel speed by 8 to 11 percent, depending on traffic volume, within the passing lane itself. The speed benefits of passing lanes persist for approximately 2 mi downstream of the passing lane.

Table 4 summarizes the percentage change in percent time spent following and average travel speed within a passing lane as a function of traffic volume. Table 5 summarizes the length of downstream roadway on which percent time spent following and average travel speed are improved by passing lanes, also as a function of traffic volume. Both tables are based on the 2000 HCM procedures.

Short passing lanes are generally more highly utilized and more cost-effective per unit length in improving traffic performance than extended sections of four-lane highway for two reasons. First, the traffic entering the passing lane from a normal two-lane section is more highly platooned, and thus “primed” to make the most of the extra lane. Second, the benefits of platoon break-up in the passing lane carryover as reduced delay on the downstream two-lane highway, until new platoons form over a number of miles. A road with regular passing lanes thus has a cyclic pattern of platooning, with zones of buildup, passing, and improved downstream operations. This cycle makes best use of a relatively small highway investment, and provides an intermediate quality of traffic operations between those of a two-lane and four-lane highway.

Table 4. Percentage Change in Average Travel Speed and Percent Time Spent Following Within a Passing Lane[1]

Directional flow rate (pc/h)	Average travel speed (mph)	Percent time spent following
0-300	+5	–58
> 300-600	+6	–61
> 600	+7	–62

Table 5. Downstream Length of Roadway Affected by Passing Lanes on Directional Segments in Level and Rolling Terrain[1]

	Downstream length of roadway affected, L_{de} (mi)	
Directional flow rate (pc/h)	Percent time spent following	Average travel speed
≤ 200	13.0	1.7
400	8.1	1.7
70	5.7	1.7
≥ 1000	3.6	1.7

Table 6 presents the range of optimal lengths for passing lanes in level and rolling terrain presented in the *Highway Capacity Manual*. Passing lanes shorter than the lengths shown in the table may not be able to satisfy all of the passing demand. Passing lanes longer than the lengths shown in the table may be inefficient because the downstream portion of the passing lane may be underutilized for passing. In most cases, it would be desirable to end the passing lane when the upper end of the optimal range is reached and introduce another passing lane downstream where passing demand has built up.

Table 6. Optimal Lengths of Passing Lanes[1,6]

Directional flow rate (pc/h)	Optimal passing lane length (mi)
100	≤ 0.50
200	> 0.50-0.75
400	> 0.75-1.00
≥ 700	> 1.00-2.00

Passing lanes have been used in the United States and in Europe on two-lane highways with a wide range of traffic volumes. Passing lanes have been found to operate safely on two-lane highways in the United States with average daily traffic (ADT) volumes up to 20,000 veh/day.[7] In Europe, passing lanes have been used on roads with ADTs up to 25,000 veh/day and, in one case, 30,000 veh/day.[8] European experience suggests that the maximum desirable flow rate for a two-lane highway with a passing lane is 1,200 veh/h in one direction of travel.[8]

Table 7 presents recommended values for length and spacing of passing lanes on lower-volume two-lane highways developed recently in research for the Texas Department of Transportation.[9]

Table 7. Recommended Values of Length and Spacing for Passing Lanes in Texas[9]

Two-way ADT (veh/day)		Recommended passing lane length (mi)	Recommended distance between passing lanes (mi)
Level terrain	Rolling terrain		
≤ 1,950	≤ 1,650	0.8-1.1	9.0-11.0
2,800	2,350	0.8-1.1	4.0-5.0
3,150	2,650	1.2-1.5	3.8-4.5
3,550	3,000	1.5-2.0	3.5-4.0

Evaluation of Specific Passing Lane Configurations

The HCM analysis procedures for rural two-lane highways include procedures for assessing the effect of passing lanes on level of service. These procedures were newly developed for the 2000 edition of the HCM and they address only the simplest of added lanes—an isolated passing lane with nothing downstream that would interrupt the traffic operational effects of the passing lane (e.g., no developed areas, speed zones, or other added lanes downstream of the passing lane being evaluated). The traffic operational effects of passing lanes that are not isolated and for combinations or systems of passing lanes along a two-lane highway can best be assessed with a computer simulation model.

Traffic Simulation Model

TWOPAS is a microscopic computer simulation model of traffic on two-lane highways developed for the Federal Highway Administration (FHWA)[10] and is the most widely used traffic simulation model for two-lane highways in the United States. TWOPAS simulates the movement of every vehicle and driver on the roadway and updates the position and speed of every vehicle once per second. Drivers make decisions to speed up, slow down, or pass one another based on the driver's desired speed, the roadway alignment, and the presence and behavior of other traffic on the roadway. TWOPAS simulates a variety of vehicle types whose performance characteristics can be specified including five types of passenger cars, four types of trucks, and four types of recreational vehicles.

TWOPAS includes the capability to simulate two-lane roadway sections with any arrangement of passing and no-passing zones and added passing lanes along a highway corridor. Comparisons can be made between the existing alignment and cross section of a highway corridor and various passing lane alternatives by taking advantage of the TWOPAS capability to make "clone" runs in which exactly the same sequence of vehicles and drivers can be run over different geometric and traffic control alternatives.

TWOPAS provides traffic operational performance measures for each alternative evaluated, including percent time spent following and average travel speed, which are used in the HCM to define level of service. In fact, the current HCM procedures for two-lane highways were developed with TWOPAS, so it provides results that are consistent with the HCM.

TWOPAS simulates traffic on a roadway section, but does not address the operation of turning movements on and off the road at intersections. This limitation makes TWOPAS appropriate for analysis of rural highway sections, where turning volumes are relatively how, but inappropriate for two-lane highway sections in towns, where turning volumes are higher. TWOPAS is, therefore, appropriate for the investigation of passing lanes, which are generally located in rural areas outside of towns. A TWOPAS feature to simulate turning movements at intersections and driveways is currently under development.

In addition to two-lane highways and two-lane highways with added passing lanes, TWOPAS can evaluate short sections of roadway with a four-lane cross section, where passing lanes overlap or have been built side by side.

The only available computer simulation model of two-lane highway traffic operations, in addition to TWOPAS, is TRARR. The TRARR model was developed by ARRB Transport Research, Ltd., formerly known as the Australian Road Research Board. TRARR has been used to evaluate passing lanes in the United States and Canada, but uses a vehicle fleet originally developed for Australian roads that may not be completely appropriate for North American roads.

Traffic Simulation Example

A traffic simulation example is presented to illustrate the traffic operational effectiveness of passing lanes on two-lane roads. This example was prepared by MRI as part of NCHRP Project 20-7(139) using the TWOPAS model.(8) A set of representative roadway types was included in the analyses:

- Two-lane roadway with no passing lanes
- Two-lane roadway with minimal passing lane frequency
- Two-lane roadway with intermediate passing lane frequency
- Two-lane roadway with continuously alternating passing lanes

Each representative roadway section is 15 mi in length. The two-lane roadway with minimal passing lane frequency consists of two 1-mi passing lanes in each direction of travel, separated by a distance of 7 mi. The two-lane roadway with intermediate passing lane frequency consists of four 1-mi passing lanes in each direction of travel, each separated by a distance of 3 mi. The roadway with continuously alternating passing lanes consists of one 1.5-mi passing lane followed by six 1-mi passing lanes in each direction of travel, each separated by a distance of 1 mi in length. Figure 6 and Table 8 summarize the layout of the roadways that were compared.

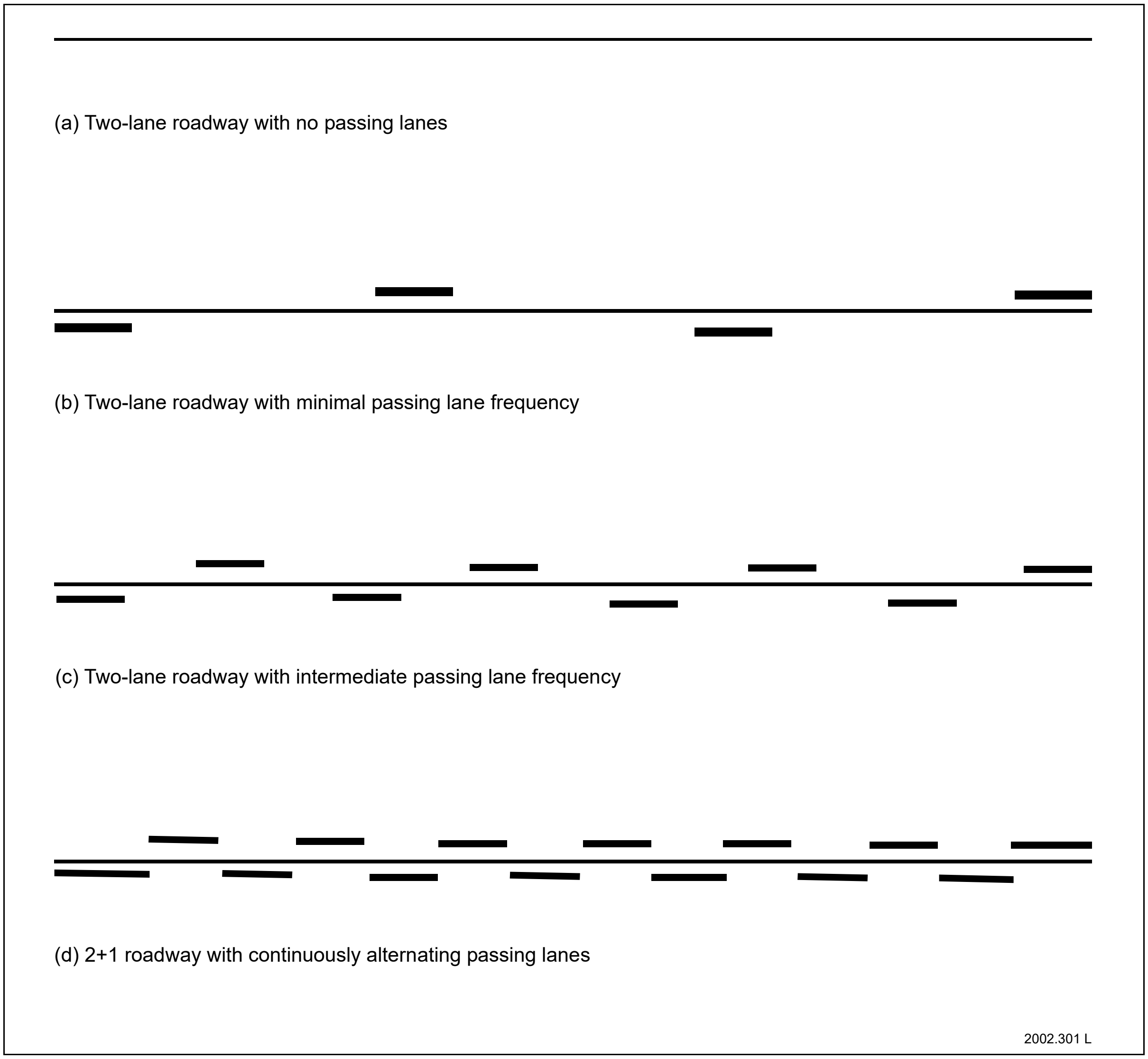


Figure 6. Layout of Roadways Analyzed by TWOPAS[8]

Table 8. Arrangement of Passing Lanes on Roadways Analyzed by TWOPAS[8]

Passing lane frequency	Total roadway length (mi)	Number of passing lanes in each direction of travel	Length of each passing lane (mi)	Spacing between passing lanes in each direction of travel[a] (mi)	Percentage of total roadway length with passing lanes in each direction of travel
None	15	0	–	–	0
Minimal	15	2	1	7	13
Intermediate	15	4	1	3	27
Continuously alternating (2+1)	15	7	1[b]	1	47

[a] Distance from end of one passing lane to beginning of the next.
[b] First passing lane in each direction of travel = 1.5 mi

The comparison was made with the TWOPAS model. Traffic operational analyses were performed for both level and rolling terrain and for a variety of combinations of traffic volume and directional split. Specifically, the analyses included traffic volumes ranging from 400 to 2,800 veh/h in each direction. Three combinations of directional split were analyzed: 50/50, 60/40, and 70/30. The traffic composition consisted of four percent trucks and three percent recreational vehicles.

Table 9 summarizes the results of the level of service comparison. This comparison shows that two-lane highways with passing lanes provide a definite improvement in level of service over two-lane highways without passing lanes. The improvement can be quite pronounced in that, at medium and high volumes, a roadway with continuously alternating passing lanes will provide an improvement by two levels of service over a conventional two-lane highway without passing lanes. A two-lane highway with less frequent passing lanes typically provides an improvement of one level of service over a conventional two-lane highway. The table suggests that any given design level of service, such as level-of-service B or level-of-service C, can be maintained over time through staged construction of passing lanes, as traffic volumes increase.

Table 9. Comparison of Level-of-Service Analysis Results[8]

Two-way volume (veh/hr)	Level-of-service by passing lane frequency			
	None	Minimal	Intermediate	Continuously alternating (2+1)
50/50 Directional Split				
400	B	A	A	A
800	C	C	B	B
1,200	D	C	C	B
1,600	D	D	C	B
2,000	E	D	D	C
2,400	E	D	D	C
2,800	E	E	D	C
60/40 Directional Split				
400	B	A	A	A
800	C	B	B	B
1,200	D	C	C	B
1,600	D	D	C	B
2,000	E	D	D	C
2,400	E	D	D	C
2,800[a]	–	–	–	–
70/30 Directional Split				
400	B	A	A	A
800	C	B	B	B
1,200	D	C	C	B
1,600	D	D	C	C
2,000	E	D	D	C
2,400	–	–	–	–
2,800[a]	–	–	–	–

[a] Combination of two-way volume and directional split exceeds the capacity of a two-lane highway.

Passing Lanes vs. Four-Lane Highways

As noted earlier, two-lane highways with passing lanes can serve two-way design volumes up to 2,800 pc/h, and one-way design volumes up to 1,700 pc/h, at level-of-service C, depending on the frequency of passing lanes provided. European experience suggests that it may be desirable to limit the traffic volumes on two-lane highways with passing lanes to 1,200 pc/h to preserve the effective operation of lane drops.[8] However, for many NHS routes, the four-lane divided highway may provide substantial excess capacity that is not really needed. Figure 7 illustrates that, for the cost of building 10 mi of four-lane divided highway, it should be possible to build many more miles of two-lane highway with passing lanes, while still meeting a specified level of service goal.

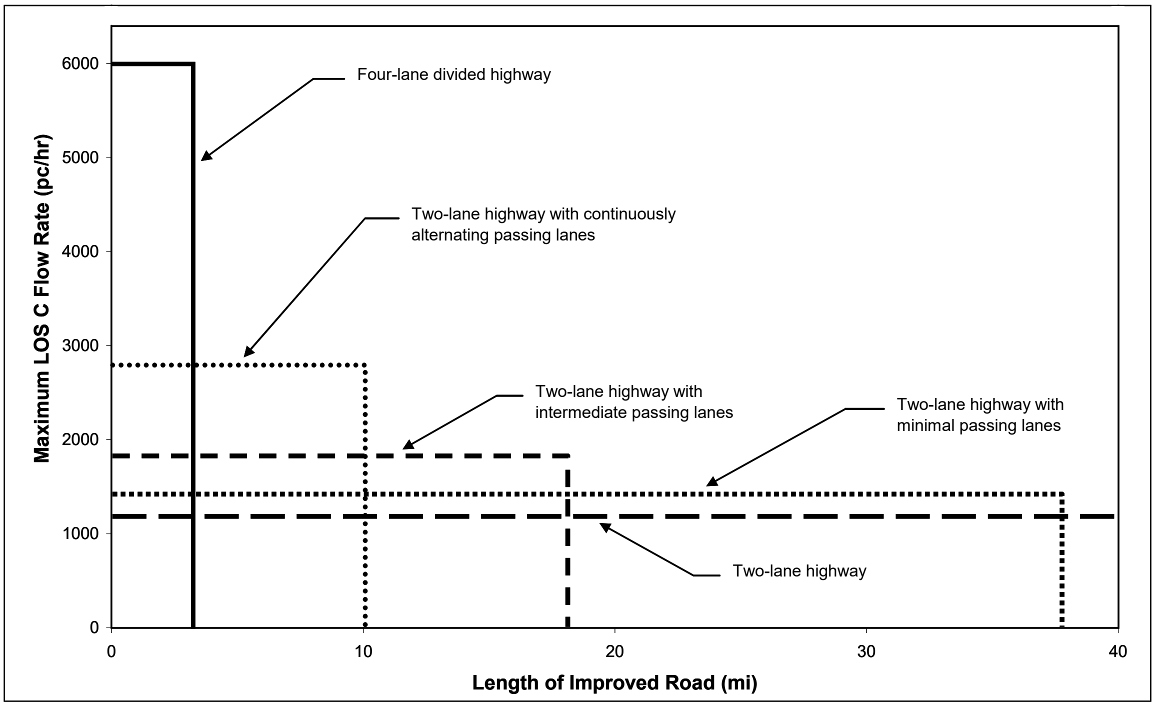


Figure 7. Conceptual Comparison of Service Volumes Provided by Two-Lane and Four-Lane Facilities

Passing lanes also lend themselves well to staged construction. Initially, a few passing lanes spaced at, say, 8-mi intervals in each direction of travel, may be provided. As traffic volumes grow, intermediate passing lanes may be added to reduce the passing lane interval to 4 mi in each direction of travel. Finally, passing lanes can be provided nearly continuously with passing lanes at intervals of 2 mi in each direction of travel.

An advantage of staged construction is that the plan is less dependent on the accuracy of traffic volume forecasts. If a large increase in traffic volumes that has been forecast never materializes, the next stage of passing lane development need not be built.

With a four-lane highway, the entire investment is made up front and that investment may or may not be borne out by future traffic volume increases.

Benefit-Cost Analysis

A benefit-cost analysis conducted by Taylor and Jain[11] for the Michigan Department of Transportation considered the traffic volume levels at which passing lanes would be economically warranted. The benefits considered in this evaluation were accident reduction and travel time savings (based on TWOPAS model results); the cost considered was the construction cost of the passing lane improvement. Taylor and Jain found that for a roadway with a 4 percent grade, 10 percent trucks, and average trip type (combining both work and nonwork trips), passing lanes were cost-effective for two-lane highways with ADTs over 6,500 veh/day. On roadways where work trips dominate, the comparable threshold ADT value is 4,500 veh/day. This evaluation used a discount rate of 5 percent to represent the time value of money; under present economic conditions a lower discount rate (say, 4 percent) would be more appropriate, which would slightly reduce the ADT thresholds reported above.

Section 5.
Safety Effectiveness of Passing Lanes

Safety evaluations have shown that passing lanes and short four-lane sections reduce accident rates below the levels found on conventional two-lane highways. The results of past safety research concerning passing lanes is reviewed below. A new evaluation of the safety effectiveness of passing lanes using Missouri data is presented in Section 9 of this report.

Overall Safety Effectiveness

Table 10 compares the results of two before-after evaluations of passing lane installation. A California study by Rinde[12] 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[7] 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 indicate that passing lane installation reduces accident rates by 25 percent.

Table 10. Accident Reduction Effectiveness of Passing Lanes[7,12]

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[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 11 shows the results of an evaluation of the safety effectiveness of passing lanes in Michigan by Taylor and Jain.[11] The percentage differences in accident rates per million veh-mi of travel shown in the table are based on comparison of similar sites with and without passing lanes rather than on before-after studies.

Table 11. Percentage Difference in Accident Rate Between Two-Lane Highways in Michigan With and Without Passing Lanes (Adapted From Ref. 11)

Traffic volume level (veh/day)	Percentage difference in accident rate for two-lane highway with passing lane by accident severity level[a]		
	Fatal	Injury	Total[b]
0-5,000	–75	–31	–13
5,001-10,000	–80	–20	–9
10,001-15,000	–16	–42	–15

[a] Negative percentage difference indicates that two-lane highways with passing lanes experience fewer accidents.
[b] Includes fatal, injury, and property-damage-only accidents.

Safety of Continuously Alternating Passing Lanes

A recent review of European safety experience for two-lane highways with continuously alternating passing lanes found results that were generally comparable to U.S. experience. Germany reported that accident frequency on two-lane highways with passing lanes was 28 percent less for total accidents and 36 percent less for fatal and injury accidents than comparable two-lane highways. In Finland, fatal and injury accidents in passing lanes were reported to be 11 percent lower than on comparable two-lane roads and, in Sweden, fatal and serious injury accidents were reduced by 55 percent after passing lane installation.(8)

Lane Addition and Lane Drop Transitions

Harwood and St. John(7) 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.

Safety of Passing by Opposing Direction Vehicles

An evaluation by Harwood and St. John(7) 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 where adequate sight distance was available.(9) 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/h 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 highways.

Safety of Intersections Within Passing Lanes

Mutabazi et al.[13,14] in research for the Kansas Department of Transportation found that intersections located within passing lanes had lower traffic conflict rates than intersections located outside of passing lanes. Furthermore, this research found no difference in traffic conflict rate between intersections located immediately downstream of a passing lane and intersections located some distance away from the passing lane. Despite their finding, Mutabazi et al. recommend caution in locating intersections within passing lanes. Higher-volume intersections and intersections in the lane addition and lane drop areas are discouraged; in general, it is recommended that intersections be located near the middle of a passing lane, rather than near the ends. Where higher-volume intersections or driveways are present within a passing lane, the provision of left-turn lanes should be considered.

Safety of Short Four-Lane Sections

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.[7] 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 of Relative Accident Rates

Table 12 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.

Table 12. Relative Accident Rates for Improvement Alternatives[3]

Alternative	All accidents	Fatal and injury accidents
Conventional two-lane highway	1.00	1.00
Passing lane section	0.75	0.70
Short four-lane section	0.65	0.60

Section 6.
Geometric Design of Passing Lanes

Geometric design of passing lanes should consider lane and shoulder widths, lane addition and lane drop taper designs, and intersection treatments. This section addresses these geometric design elements.

Lane Width

The policies of most highway agencies specify that the lane widths in a passing lane section should normally be the same as the lane widths on the adjacent sections of two-lane highway. Lane widths of 12 ft are used by most states. Specifically, Arkansas and Minnesota normally use 12-ft lanes in passing lane sections. Nevada uses the lane width criteria for two-lane highways in the AASHTO *Green Book*. Oregon uses the same lane widths in passing lanes as for normal two-lane highway construction. Texas uses lane widths in the range from 10 to 12 ft, a desirable lane width of 12 ft and a minimum lane width equal to the lane width of the adjacent two-lane roadway.

MoDOT design criteria indicate that 12-ft lanes are used for all highways except for collector and local roads with design ADT less than 400 veh/day. While MoDOT policy includes no specific design criteria or typical cross sections for passing lane sections, the use of 12-ft lanes would be consistent with existing MoDOT policies.

Shoulder Width

Highway agencies have used shoulder widths ranging from 3 to 10 ft on either side of the highway in passing lane sections. Whenever practical, the shoulder width in a passing lane section should not be narrower than the shoulder width on the adjacent sections of two-lane highway.

In the past, some highway agencies have accepted narrow shoulder widths in passing lane and short four-lane sections where conversion from a normal two-lane highway section with wide shoulders could be accomplished at low cost by restriping or with minimal construction work by state maintenance forces. However, the formal policies of most highway agencies concerning passing lanes provide for shoulder widths equivalent to those used in new construction of two-lane highways. For example, Arkansas uses 6-ft shoulder widths on the passing lane side and 8-ft shoulders on the opposite side within passing lane sections. Minnesota uses 6-ft minimum and 10-ft desirable shoulder widths for passing lanes; Minnesota policy specifically permits the use of both paved and composite (part paved/part gravel) shoulders in passing lane sections; full 10-ft shoulders are required by Minnesota in the lane drop transition area and, desirably, for 500 ft beyond. Oregon uses 3-ft minimum and 5-ft desirable shoulder widths in passing lane sections (4 ft minimum and 5 ft desirable if a bikeway is provided).

Current MoDOT design policy for principal arterials with design ADTs over 1,700 veh/day (Typical Section D-60) and two-lane principal arterials with design ADTs less than 1,700 veh/day (Typical Section D-63) include 10-ft shoulder widths. Thus, the use of 10-ft shoulders in passing lanes is most consistent with existing MoDOT policies. Lesser shoulder widths may be used where this would substantially reduce costs. In no case should the shoulder width be less than 4 ft.

Lane Addition Transition Areas

The lane addition transition area at the beginning of a passing lane should be designed to encourage safe and efficient traffic operations. Many highway agencies have used relatively short lane addition tapers. 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.

There is no *Green Book* or 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 length for a lane addition taper recommended in the FHWA *Informational Guide* is half to two-thirds of the length of a lane drop taper, or 360 to 480 ft for a 60-mph design speed presented above.

Highway agency practices for lane addition taper rates vary from 25:1 with a minimum length of 165 ft in Oregon to 50:1 in Minnesota. Both Oregon and Minnesota use shorter tapers for passing lane additions than for lane drops. Arkansas uses a formula for the length of both lane addition and lane drop tapers which specifies that the taper length in fact should be equal to the width of the added lane in feet times the design speed in mph; this is equivalent to the MUTCD lane drop transition formula except that the speed used is the design speed rather than the 85th percentile speed. MoDOT has no established design criteria for the length of lane addition tapers for passing lanes but does have criteria for two-lane to four-lane highway transitions.

Safe and effective passing lane operations require adequate sight distance on the approach to lane addition tapers. Lack of 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. Most highway agencies do not have sight distance criteria for lane addition transition areas that differ from their established stopping sight distance criteria for normal two-lane highways. However, Minnesota specifies minimum passing sight distance of 1,000 ft (using the MUTCD definition) on the approach to both lane addition and lane drop transitions.

Passing lanes work most effectively 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 may be gained from passing lanes if most drivers continue directly into the left lane at the lane addition transition. Thus, it should not appear to drivers that the left lane of the passing lane section is a direct extension of their normal lane on the upstream two-lane highway. The geometric design of the lane addition transition should encourage drivers to enter the right lane. This desirable behavior can be reinforced through signing and marking as described in Section 7.

Lane Drop Transition Area

The lane drop transition is one of the most critical design elements of a passing lane. From a traffic operational standpoint, the lane drop can act as a bottleneck because two lanes of traffic are forced to merge into one lane. Merging can be to the left, where slower vehicles in the outer lane being terminated merge to the inside lane, or to the right, where the passing vehicles in the inner lane merge to the slower stream in the outer lane. Currently, there is no research to support a preference of one design over the other.

The transition taper at the lane drop should be designed to encourage safe and efficient operation. Most highway agencies use a lane drop taper length computed from the MUTCD[6] formula $L = WS$, where L is the taper length in ft, W is the width of the dropped lane in ft, and S is the off-peak 85th percentile speed in mph. For example, at the termination of a 12-ft lane, the MUTCD taper length for a 60-mph design speed is 720 ft. Arkansas uses the MUTCD taper length formula to determine the length of lane drop tapers, but the speed used is the design speed rather than the 85th percentile speed. For passing lanes, Oregon uses a standard lane drop taper with a 50:1 taper rate. Minnesota uses a standard lane drop taper with a 60:1 taper rate.

Safe and effective passing lane operations require adequate sight distance on the approach to lane drop tapers. When sight distance approaching the lane drop taper is limited, vehicles may merge too early or too late, resulting in erratic behavior and poor utilization of the passing lane. Most highway agencies do not have sight distance requirements for lane drop transition areas that differ from their established stopping sight distance criteria for normal two-lane highways. However, Minnesota specifies minimum passing sight distance of 1,000 ft (using the MUTCD definition) on the approach to both lane addition and lane drop transitions.

A wide shoulder is desirable at the lane drop taper to provide a recovery area should drivers encounter a merging conflict.

Intersection Treatments

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. In fact, intersections can often be used effectively to provide a buffer area between opposing passing lanes. Low-volume intersections and driveways do not usually create problems in passing lanes. Where the presence of higher-volume intersections and driveways within a passing lane cannot be avoided, special provisions for turning vehicles, such as exclusive left-turn lanes, should be considered. The prohibition of passing by vehicles traveling in the opposing direction should also be considered on passing lane sections with higher-volume intersections and driveways.

Some highway agencies place signs in advance of intersections within passing lane sections to warn motorists of possible left-turning vehicles.

Section 7. Effective Signing and Marking of Passing Lanes

The signing and marking of passing lanes is partially addressed in the MUTCD,[6] which indicates the appropriate centerline markings for passing lanes and the signing and marking of lane drop transition areas. The following discussion addresses the extension of the MUTCD criteria to provide a consistent set of traffic control devices for use at passing lanes. Figure 8 presents the signing and marking recommendations from the FHWA *Informational Guide*.

Signing

There are four places on a two-lane highway with passing lanes where signing is needed to convey information to drivers:

- In advance of the passing lane
- At the lane addition
- In advance of the lane drop
- In the opposing lane

Advance Signing

The FHWA *Informational Guide* recommends that a sign with the legend PASSING LANE 1/2 MILE be placed 0.5 mi in advance of each passing lane (see Figure 9). This sign provides advance notification 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 2 to 5 mi 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 assured passing opportunity. 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[15] found, for example, that when forced to follow a slow moving vehicle for up to 5 mi, almost 25 percent of drivers made an illegal pass in a no-passing zone.

Highway agency practice for use of signing in advance of passing lanes varies. Some highway agencies use a black-on-white regulatory sign for this application, while others use a white-on-green guide sign. Arkansas does not use advance signing. Minnesota uses an advance sign 0.5 mi upstream of passing lanes and notes that advance signs 2 to 5 mi upstream of a passing lane are desirable. Nevada has not used advance signing in the past, but is beginning to introduce signs 1 to 2 mi in advance of passing lanes on one major two-lane highway. Kansas has always used an advance sign 0.5 mi upstream of a passing lane. Since 1995, Kansas has recommended that an additional

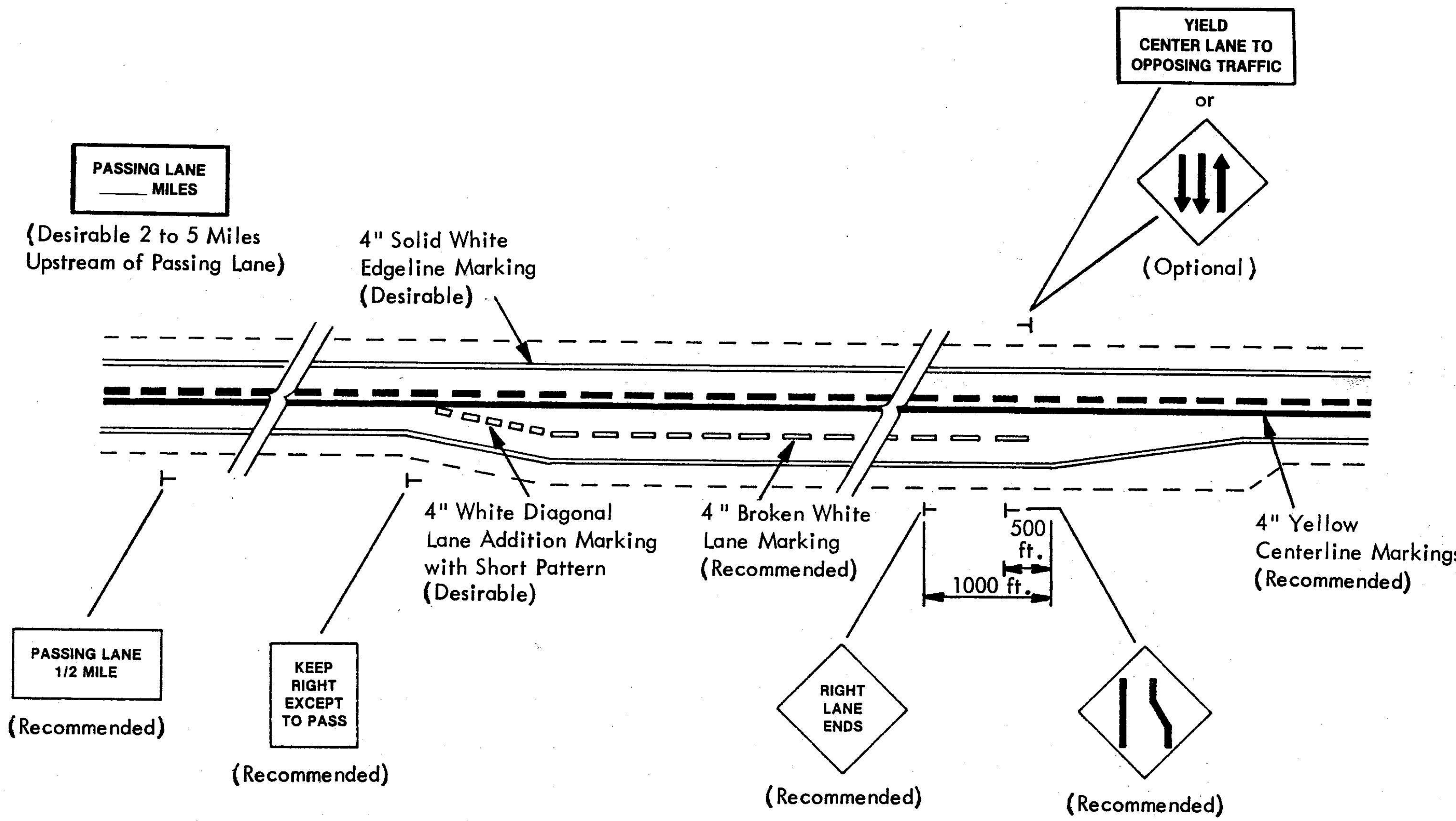


Figure 8. Signing and Marking Practices for Passing Lanes Recommended in the FHWA *Informational Guide*[3]

advance sign be placed 2 mi in advance of a passing lane. Oregon uses advance signing either 0.5 or 1 mi upstream of passing lanes. Texas prefers to use an advance sign 2 mi upstream of passing lanes. Washington uses an advance sign 0.5 mi upstream of a passing lane. Washington also considers it desirable to place a sign NEXT PASSING LANE X MILES immediately downstream of the lane drop of a passing lane.

Figure 9. Typical Sign with the Legend "Passing Lane ½ Mile"

Lane Addition Signing

The FHWA *Informational Guide* recommends that a black-on-white regulatory sign with the legend KEEP RIGHT EXCEPT TO PASS, as illustrated in Figure 10, 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 (R4-3—see Figure 11), 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 (R4-5—see Figure 12), are used by some agencies for climbing lanes, but 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.

Figure 10. Black-on-White Regulatory Sign With the Legend "Keep Right Except to Pass"

Figure 11. Black-on-White Regulatory Sign With the Legend "Slower Traffic Keep Right" (R4-3)

Figure 12. Black-on-White Regulatory Sign With the Legend "Trucks Use Right Lane" (R4-5)

Current practices of highway agencies for signing of the lane addition area are about equally split between use of the KEEP RIGHT EXCEPT TO PASS and SLOWER TRAFFIC KEEP RIGHT signs.

Lane Drop Signing

The MUTCD[(6)] requires a black-on-yellow warning sign in advance of a lane drop. The advance warning sign can be a symbol sign (W4-2—see Figure 13) or a text sign that states either RIGHT LANE ENDS (W9-1—see Figure 14) or LANE ENDS MERGE LEFT (W9-2—see Figure 15). MUTCD Table 2C-4 provides guidance on how far in advance of a lane drop the warning sign should be placed. Many highway agencies use two warning signs in advance of the lane drop transition areas of passing lanes. When two warning signs are used, the first advance warning sign (with the legend RIGHT LANE ENDS) is generally located approximately 1,000 ft in advance of the lane drop taper. The second advance warning sign is generally the lane reduction transition symbol sign (Figure 13), which is typically located 500 ft in advance of the lane drop taper. A number of states use the two-way traffic sign (W6-3—see Figure 16) downstream of the lane drop transition to remind motorists that they have returned to a conventional two-lane highway.

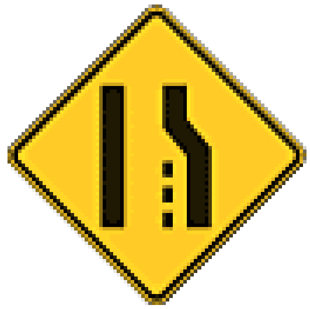


Figure 13. Black-on-Yellow Lane Reduction Transition Symbol Sign (W4-2)

Figure 14. Black-on-Yellow Warning Sign With the Legend "Right Lane Ends" (W9-1)

Figure 15. Black-on-Yellow Warning Sign With the Legend "Lane Ends Merge Left" (W9-2)

Figure 16. Black-on-Yellow Two-Way Traffic Warning Sign (W6-3)

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 (R4-1—see Figure 17), the PASS WITH CARE sign (R4-2—see Figure 18), and the pennant-shaped NO PASSING ZONE sign (W14-3—see Figure 19), usually continue this practice in the opposing direction of travel at passing lane sites. Where passing by vehicles traveling in the opposing direction is permitted, some agencies, such as the Oregon Department of Transportation, 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 20. This sign does not identify whether passing by vehicles traveling in the opposing direction is permitted or prohibited, but it does alert drivers that there are two lanes of oncoming traffic.

Figure 17. Black-on-White Regulatory Sign With the Legend "Do Not Pass" (R4-1)

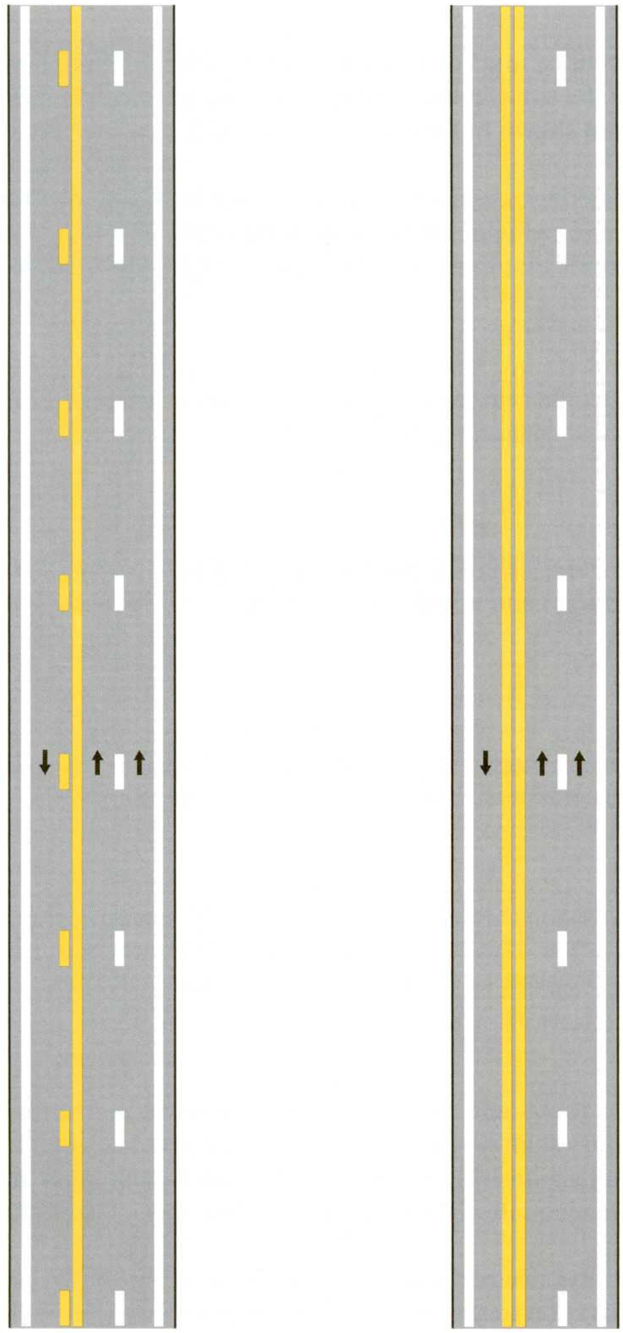
Figure 18. Black-on-White Regulatory Sign With the Legend "Pass With Care" (R4-2)

Figure 19. Black-on-Yellow Warning Sign With the Legend "No Passing Zone" (W14-3)

Figure 20. Black-on-Yellow Three-Arrow Sign Used in Australia[3]

Marking

Two alternative markings for passing lane sections with two lanes in one direction of travel and one lane in the opposite direction of travel are presented in the MUTCD and are illustrated in Figure 21. 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 of travel. 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.



a - Typical three-lane, two-way marking with passing permitted in single-lane direction

b - Typical three-lane, two-way marking with passing prohibited in single-lane direction

Figure 21. Typical Passing Lane Marking Applications (MUTCD Figure 3B-3)[(6)]

Passing by vehicles traveling in the opposing direction to a passing lane may be either permitted or prohibited, as illustrated in Figure 21. A number of highway agencies allow passing by vehicles in the opposing (single-lane) direction to a passing lane where sight distance is adequate. A study by Harwood and St. John[7] 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. No-passing zones should be marked for the opposing direction of travel where warranted by the same criteria used in marking normal two-lane highways, specified in MUTCD Section 3B.02.[5] One highway agency, the Oregon Department of Transportation, requires 2,000 ft of passing sight distance—double the normal passing sight distance requirement of 1,000 ft for a 60-mph highway—in order for passing by vehicles in the opposing direction to a passing lane to be permitted.

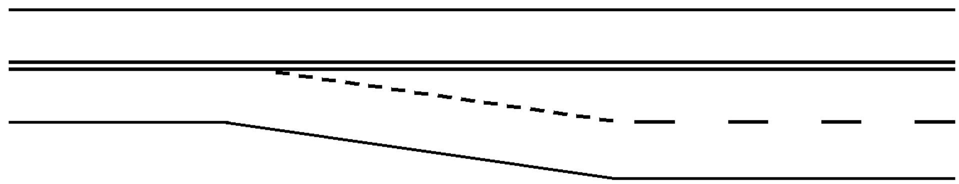
About half of the state highway agencies that use passing lanes prohibit passing by vehicles traveling in the opposing direction at all passing lane sites. While this practice may be appropriate under certain circumstances, prohibition of passing in the opposing direction of travel, regardless of sight distance, can negatively affect both the traffic operational and safety performance of passing lane sections. Blanket use of a double yellow center line unnecessarily reduces the level of service in the opposing direction of travel and some drivers traveling in that direction may be tempted to pass in areas of good sight distance that would otherwise be excellent passing zones. Some agencies have chosen 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 traveling 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 Marking

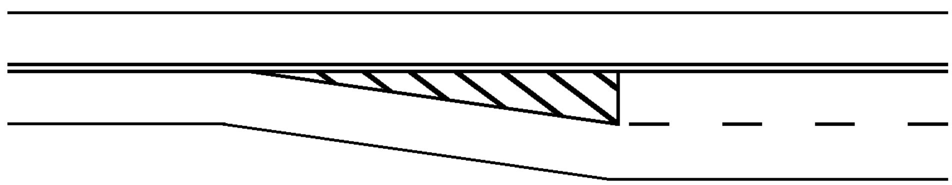
The MUTCD[6] does not provide any specific guidance for marking a lane addition transition area and most highway agencies do not use any special marking for lane additions of passing lanes. However, individual highway agencies have developed special markings for the lane addition transition area which are illustrated in Figure 22.

As noted above in Section 6, passing lanes work most effectively 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. Two markings have been used to encourage drivers to enter the right lane of the passing lane section. These are a white diagonal marking illustrated in Figures 8 and 22(a) and a yellow-median marking illustrated in Figure 22(b).

Several highway agencies have found the white diagonal marking illustrated in Figure 22(a) to be effective in guiding most drivers into the right lane so that the left lane is used for passing slower vehicles. Drivers who desire to pass immediately upon entering the passing lane are permitted to cross the diagonal marking.



(a) Diagonal Dashed Marking



(b) Median Island Marking

Figure 22. Lane Addition Transition Markings

The white diagonal marking has been used in Australia and California and has been evaluated in research in Kansas and Texas. This marking was used by several highway districts in California, although it was never adopted as state-wide policy. However, recent research in California concluded that the traffic operational benefits of the diagonal marking were too small to justify its use.(16,17) Earlier California research by May et al.(18) found an effect of the diagonal marking on driver lane choice at the lane addition, but little effect on percent time spent following at the downstream end of the passing lane. Recent research in Texas, where the diagonal marking was installed at the lane addition of existing passing lanes found substantially increased usage of the right lane by slower vehicles.(9) The use of the diagonal marking has been recommended for future use in both Kansas and Texas.(9,14)

Minnesota recommends the use of the yellow median marking shown in Figure 22(b) to encourage drivers to enter the right lane of a passing lane section.

Lane Drop Marking

Pavement markings in the lane drop transition area should be provided in accordance with MUTCD Section 3B.09,(6) as illustrated in Figure 23. The use of a pavement edge marking in the lane drop transition area is recommended.

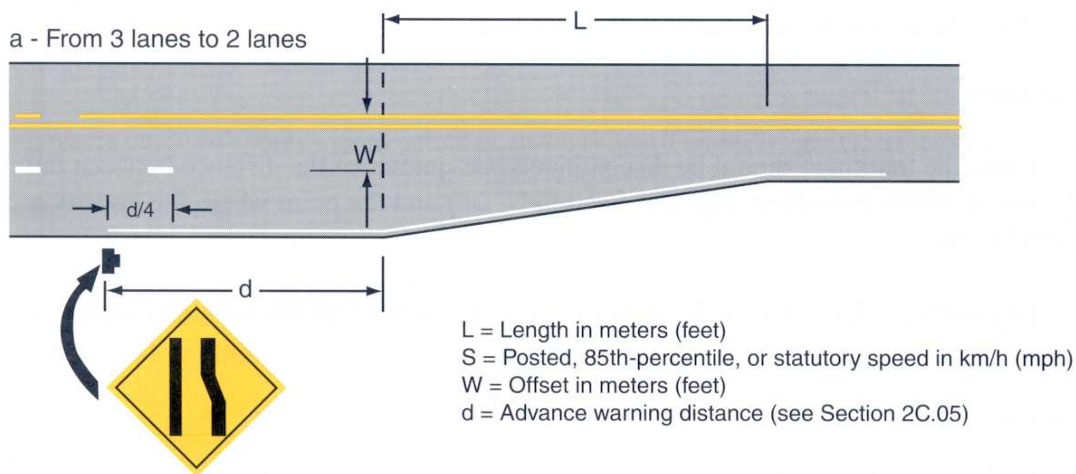


Figure 23. Typical Lane Reduction Transition Markings (MUTCD Figure 3B-12)[(6)]

Section 8.
Traffic Operational Analysis

This section of the report presents an evaluation of the traffic operational effectiveness of existing passing lanes on rural two-lane NHS roadways in Missouri.

Passing Lanes on Missouri NHS Routes

The locations of existing passing lanes were identified from MoDOT's existing roadway inventory data files and from telephone contacts with MoDOT's headquarters and MoDOT's district offices. All of the existing passing lanes that were identified are located in Districts 5, 8, and 9 and are summarized in Table 13. As shown in the table, there are a total of 28 existing passing lanes on rural NHS roadways with a total length of 29.3 mi. The average length of the existing passing lanes is 1.05 mi. Several of the existing passing lanes are located on steep upgrades to serve as climbing lanes for slow-moving trucks. Seven of the 28 existing passing lanes are on roadways that are currently under construction for conversion to four-lane divided highways. Each existing passing lane shown in Table 13 was reviewed either in the field or on MoDOT's photolog.

Study Locations Selected for Traffic Operational Analysis

Within each of the three districts (Districts 5, 8, and 9), a representative roadway section of existing passing lanes was selected for consideration in a traffic operational evaluation. The objective of the evaluation was to estimate the traffic operational benefits provided by existing passing lanes. The representative roadway sections were rural two-lane highways ranging between 2.8 and 13.0 mi in length. Each evaluation section included between two and five passing lanes that ranged between 0.40 and 2.92 mi in length. Each roadway section was selected so that there were no major intersections located within the section. Also, each section had a uniform speed limit of at least 55 mph throughout the section. Table 14 presents the three roadway sections that were selected for evaluation.

For each roadway section, existing alignment and cross section data were obtained from as-built plans or other available records. The results of traffic volume counts, speed studies, or other traffic study data that MoDOT had on file were also obtained.

Traffic Operational Analysis Approach

A level of service analysis was performed to evaluate:

- the level of service for the current configuration (with passing lanes) and traffic volume
- the level of service for the current traffic volume if the passing lanes were not present and the roadway was a conventional two-lane highway

Table 13. Existing Passing Lanes on Rural NHS Routes in Missouri

District	County	Route	Direction of travel	Continuous Log Mile[a] (approximate) From	To	Length (mi)
5	Camden	US 54	WB	96.31	97.05	0.74
5	Camden	US 54	WB	103.99	104.39	0.40
5	Camden	US 54	WB	105.93	106.60	0.67
5	Camden	US 54	EB	108.33	109.21	0.88
5	Miller	US 54	WB	126.46	127.20	0.74[b]
5	Miller	US 54	EB	127.53	128.79	1.26[b]
5	Osage	US 63	SB	166.15	167.24	1.09
5	Maries	US 63	NB	191.20	191.78	0.58
5	Maries	US 63	SB	193.34	193.71	0.37
5	Maries	US 63	SB	195.59	197.24	1.65
5	Osage	US 50	WB	160.22	160.45	0.23
8	Polk	MO 13	SB	188.95	190.42	1.47[b]
8	Polk	MO 13	SB	192.94	195.28	2.34[b]
8	Polk	MO 13	NB	195.28	198.20	2.92[b]
8	Polk	MO 13	SB	198.43	199.67	1.24[b]
8	Polk	MO 13	NB	199.67	200.95	1.28[b]
9	Shannon	US 60	EB	207.58	208.18	0.60
9	Shannon	US 60	WB	207.78	208.63	0.85
9	Shannon	US 60	EB	208.88	210.25	1.37
9	Shannon	US 60	WB	209.51	210.84	1.33
9	Shannon/Carter	US 60	EB	211.10	212.11	1.01
9	Carter	US 60	WB	212.84	214.49	1.65
9	Carter	US 60	EB	216.96	217.79	0.83
9	Carter	US 60	WB	217.40	218.28	0.88
9	Carter	US 60	EB	223.15	223.8	0.65
9	Carter	US 60	EB	225.18	225.87	0.69
9	Carter	US 60	EB	226.84	227.62	0.78
9	Carter	US 60	WB	227.33	228.12	0.79

ations shown are continuous log miles in the southbound or eastbound direction even for passing lanes in the northbound or westbound dire
ting passing lane sites currently under construction for conversion to a four-lane divided highway.

Table 14. Representative Roadway Sections Included in the Analysis

District	County	Route	Continuous log mile (approximate) From	Continuous log mile (approximate) To	Length (mi)	Existing passing lanes Number	Existing passing lanes Tot. length
5	Camden	US 54	103.84	106.67	2.83	2	1.07
8	Polk	MO 13	188.45	201.45	13.00	5	9.25
9	Shannon	US 60	206.77	212.45	5.68	5	5.16

The level of service for a two-lane highway is defined by two parameters:

- *percent time spent following*, which represents the percentage of their total travel time that drivers spend delayed in platoons behind slower vehicles on a section of two-lane highway
- *average travel speed*, which represents the average speed of traffic on a section of two-lane highway

Table 15 presents the level of service criteria from the 2000 edition of the HCM for two-lane arterial highways. Both the percent time spent following and average travel speed criteria shown in the table must be met in order for a two-lane highway to be classified as operating at a given level of service.

Table 15. Level of Service Criteria for Two-Lane Highways in Class I[1]

LOS	Percent time spent following	Average travel speed (mph)
A	≤ 35	> 56
B	> 35-50	> 50-56
C	> 50-65	> 43-50
D	> 65-80	> 37-43
E	> 80	≤ 37

Note: LOS F applies whenever the flow rate exceeds the segment capacity.

The traffic simulation model used in the traffic operational analysis was TWOPAS. Paired computer simulation runs were made for the existing alignment, with and without the passing lanes, to assess the effect of the existing passing lanes on level of service. For each condition evaluated, five replicate runs were made with different sequences of drivers and vehicles to represent the normal day-to-day variations in traffic streams.

Traffic Operational Analysis Results

For three roadway sections on rural NHS routes in Missouri—US 54, MO 13, and US 60—traffic operational analyses were performed for both the previous two-lane configuration and the existing two-lane configuration with passing lanes. The results were used to estimate the traffic operational effectiveness of existing passing lanes in Missouri.

US 54 Analysis Section

Table 16 summarizes the cross sections along the US 54 analysis section. This section is 2.83 mi in length and includes two westbound passing lanes.

Table 16. Summary of Roadway Lengths by Lane Configuration (US 54 Analysis Section)

Lane configuration	Continuous log mile (approximate) From	Continuous log mile (approximate) To	Length (mi)
Two-lane undivided	103.84	103.99	0.15
WB passing lane	103.99	104.39	0.40
Two-lane undivided	104.39	105.93	1.54
WB passing lane	105.93	106.60	0.67
Two-lane undivided	106.60	106.67	0.07
		Total	2.83

The traffic operational analysis of the US 54 analysis section was performed for 350 veh/h in each direction, which represents 10 percent of the 2001 AADT of about 7,000 veh/day. The traffic composition consisted of 10 percent trucks and 5 percent recreational vehicles.

Table 17 presents the results of the traffic operational analysis of the US 54 roadway section. For both lane configurations, the average travel speed exceeds 90 km/h (55 mph) under the conditions analyzed, so the level of service is essentially a function of just the percent time spent following criteria shown in the Table 15. As shown in Table 15, the percent time spent following criteria for LOS B ranges from 35 to 50 percent. Thus, even though the existing passing lanes do not increase the level of service by an entire level, there is a substantial improvement in the quality of traffic operations. That is, the US 54 analysis section, with existing passing lanes, currently operates in the upper portion of LOS B, nearly to LOS A. If the passing lanes had not been constructed, the analysis section would be currently operating in the lower portion of LOS B, nearly to LOS C.

This roadway is in an area with substantial recreational traffic peaks, particularly on summer weekends. It is likely that, without the passing lanes at this site, traffic operations on summer weekends would be at LOS C or lower. The exact level of service would be dependent on the direction of heavier traffic volumes.

Table 17. Summary of Traffic Operational Analysis Results for US 54 Analysis Section

Lane configuration	Percent time spent following	Average travel speed (mph)	Level of service with 2001 traffic volumes
Existing configuration (with passing lanes)	36.1	58.4	B
Two-lane configuration (without passing lanes)	46.0	57.2	B

MO 13 Analysis Section

Table 18 summarizes the cross sections along the MO 13 analysis section. This section is 13.00 mi in length and includes two northbound and three southbound passing lanes.

Table 18. Summary of Roadway Lengths by Lane Configuration (MO 13 Analysis Section)

Lane configuration	Continuous log mile (approximate) From	Continuous log mile (approximate) To	Length (mi)
Two-lane undivided	188.45	188.95	0.50
SB passing lane	188.95	190.42	1.47
Two-lane undivided	190.42	192.94	2.52
SB passing lane	192.94	195.28	2.34
NB passing lane	195.28	198.20	2.92
Two-lane undivided	198.20	198.43	0.23
SB passing lane	198.43	199.67	1.24
NB passing lane	199.67	200.95	1.28
Two-lane undivided	200.95	201.45	0.50
		Total	13.00

The traffic operational analysis of the MO 13 analysis section was performed for 530 veh/h in each direction, which represents 10 percent of the 2001 AADT of about 10,600 veh/day. The traffic composition consisted of 10 percent trucks and 5 percent recreational vehicles.

Table 19 presents the results of the traffic operational analysis of the MO 13 roadway section. For both lane configurations, the average travel speed exceeds 90 km/h (55 mph) under the conditions analyzed, so the level of service is essentially a function of just the percent time spent following criteria shown in the Table 15. The MO 13 analysis section, with existing passing lanes, currently operates at a LOS B. If the passing lanes had not been constructed, the analysis section would be currently operating at a LOS D. This roadway segment is currently under construction for conversion to four-lane divided, as part of MoDOT's commitment to provide a continuous four-lane divided highway between Kansas City and Springfield.

Table 19. Summary of Traffic Operational Analysis Results for MO 13 Analysis Section

Lane configuration	Percent time spent following	Average travel speed (mph)	Level of service with 2001 traffic volumes
Existing configuration (with passing lanes)	45.4	57.8	B
Two-lane configuration (without passing lanes)	68.4	55.9	D

Analysis of US 60 Roadway Section

Table 20 summarizes the cross sections along the US 60 analysis section. This section is 5.68 mi in length and includes two westbound and three eastbound passing lanes. At two locations, the eastbound and westbound passing lanes overlap.

The traffic operational analysis of the US 60 analysis section was performed for 225 veh/h in each direction, which represents 10 percent of the 2001 AADT of about 4,500 veh/day. The traffic composition consisted of ten percent trucks and five percent recreational vehicles.

Table 21 presents the results of the traffic operational analysis of the US 60 roadway section. For both lane configurations, the level of service is more a function of the percent time spent following criteria rather than the average travel speed criteria shown in the Table 15. The US 60 analysis section, with existing passing lanes, currently operates at a LOS A. If the passing lanes had not been constructed, the analysis section would be currently operating at a LOS C.

Table 20. Summary of Roadway Lengths by Lane Configuration (US 60 Analysis Section)

Lane configuration	Continuous log mile (approximate) From	Continuous log mile (approximate) To	Length (mi)
Two-lane undivided	206.77	207.58	0.81
EB passing lane	207.58	207.78	0.20
Overlapping EB and WB passing lanes	207.78	208.18	0.40
WB passing lane	208.18	208.63	0.45
Two-lane undivided	208.63	208.88	0.25
EB passing lane	208.88	209.51	0.63
Overlapping EB and WB passing lanes	209.51	210.25	0.74
WB passing lane	210.25	210.84	0.59
Two-lane undivided	210.84	211.10	0.26
EB passing lane	211.10	212.11	1.01
Two-lane undivided	212.11	212.45	0.34
		Total	5.68

Table 21. Summary of Traffic Operational Analysis Results for US 60 Analysis Section

Lane configuration	Percent time spent following	Average travel speed (mph)	Level of service with 2001 traffic volumes
Existing configuration (with passing lanes)	20.8	55.4	A
Two-lane configuration (without passing lanes)	52.0	51.7	C

Summary of Results

The traffic operational benefits of existing passing lanes in Missouri were estimated by conducting a traffic operational evaluation of three representative roadway sections with passing lanes. The level of service for the current configuration (with passing lanes) was compared to what the level of service would be if the passing lanes were not present and the roadway was a conventional two-lane highway. The results of the traffic operational analysis are summarized below.

US 54 Analysis Section

- Without passing lanes, the US 54 analysis section would be currently operating in the lower portion of LOS B, nearly to LOS C.
- With passing lanes, the US 54 analysis section currently operates in the upper portion of LOS B, nearly to LOS A.
- While the passing lanes on the US 54 analysis section do not actually increase the level of service by an entire level, they do provide a substantial improvement in the quality of traffic operations.

MO 13 Analysis Section

- Without passing lanes, the MO 13 analysis section would be currently operating at a LOS D.
- With passing lanes, the MO 13 analysis section currently operates at a LOS B.
- The passing lanes on the MO 13 analysis section increase the level of service by two levels (from LOS D to LOS B) and provide a substantial improvement in the quality of traffic operations.

US 60 Analysis Section

- Without passing lanes, the US 60 analysis section would be currently operating at a LOS C.
- With passing lanes, the US 60 analysis section currently operates at a LOS A.
- The passing lanes on the US 60 analysis section increase the level of service by two levels (from LOS C to LOS A) and provide a substantial improvement in the quality of traffic operations.

In summary, the results of the traffic operational evaluation confirm that passing lanes have the potential of improving overall traffic operations on two-lane highways in Missouri by breaking up traffic platoons and reducing delays caused by inadequate passing opportunities over substantial lengths of highway.

Section 9.
Safety Evaluation of Existing Passing Lanes in Missouri

A safety evaluation of existing passing lanes has been conducted for rural NHS routes in Missouri. This evaluation shows that the installation of passing lanes on existing two-lane highways can provide substantial safety benefits.

Comparison of Accident Rates for Different Roadway Types

Comparisons of accident experience for different roadway types were made with data from MoDOT's TMS database. These comparisons used accident and ADT data for the years 1997 through 2001, inclusive, for all sites on rural NHS roadways for which data were available. The roadway types included in the comparisons were conventional two-lane highways, two-lane highways with added passing lanes, and conventional four-lane divided expressways (nonfreeways).

Table 22 shows a comparison of accident experience by MoDOT district and roadway type including both intersection and nonintersection accidents. Accident frequencies and rates (per hundred million veh-mi of travel) are shown for total accidents and separately for fatal-plus-injury (F&I) accidents and property-damage-only (PDO) accidents. The table includes 1,464.7 mi of two-lane highways, 26.1 mi of two-lane highways with passing lanes in one or both directions of travel, and 1,433.8 mi of four-lane divided expressways (counting the length of four-lane divided highway separately for each direction of travel). This analysis includes all roadways of these types on the rural NHS system for which accident and ADT data are available for the period of interest. Because all of the passing lanes are located in MoDOT Districts 5, 8, and 9, the data for two-lane highways and four-lane divided highways have been summarized separately as statewide totals and as totals for Districts 5, 8, and 9.

The data in Table 22 show clearly that the existing passing lane sections operate with lower accident rates than conventional two-lane highways. Total accident rates in Districts 5, 8, and 9 are 29 percent lower for two-lane highways with passing lanes than for conventional two-lane highways. In fact, the total accident rate for passing lanes is only slightly higher than for four-lane divided expressways (88.8 vs. 80.1 accidents per hundred million veh-mi). However, two factors must be further considered to make this comparison completely fair. First, since passing lanes are usually built away from major intersections, it is preferable to compare the accident rates for these roadway types based on nonintersection accidents only. Second, since traffic volumes for two-lane highways with passing lanes are generally higher than for two-lane highways as a whole, it is desirable to account for the effect of traffic volume in making this comparison. The use of accident rates per hundred million veh-mi implicitly assumes that accident frequencies

Table 22. Accident Rates for Missouri Rural NHS Routes by Roadway Type and District

District	Total length (mi)[a]	Average two-way ADT[b] (veh/day)	Travel[b] (100 MVMT)	Number of accidents[b]			Accident rate (per 100 MVMT)[b]		
				Total	F&I	PDO	Total	F&I	PDO
Two-Lane Highways									
1	63.95	4238	4.95	543	226	317	109.8	45.7	64.1
2	149.80	4696	12.84	1113	377	736	86.7	29.4	57.3
3	163.87	4782	14.30	1290	455	835	90.2	31.8	58.4
4	106.84	4816	9.39	1486	433	1053	158.2	46.1	112.1
5	226.87	5223	21.62	3391	1231	2160	156.8	56.9	99.9
6	28.75	7384	3.87	731	284	447	188.7	73.3	115.4
7	127.62	6424	14.96	1715	634	1081	114.6	42.4	72.3
8	128.10	7303	17.07	1899	725	1174	111.2	42.5	68.8
9	223.44	4735	19.31	1974	756	1218	102.2	39.2	63.1
10	245.44	4407	19.74	2779	961	1818	140.8	48.7	92.1
Dist 5,8 & 9	578.42	5495	58.01	7264	2712	4552	125.2	46.8	78.5
Statewide	1464.68	5165	138.06	16921	6082	10839	122.6	44.1	78.5
Two-Lane Highways with Added Passing Lanes									
5	7.88	8138	1.17	105	35	70	89.7	29.9	59.8
8	9.25	9787	1.65	131	50	81	79.3	30.3	49.0
9	8.92	4238	0.69	76	26	50	110.2	37.7	72.5
Dist 5,8 & 9	26.05	7388	3.51	312	111	201	88.8	31.6	57.2
Statewide	26.05	7388	3.51	312	111	201	88.8	31.6	57.2
Four-Lane Divided Expressways									
1	107.41	7572	7.42	488	199	289	65.8	26.8	38.9
2	127.02	6890	7.99	688	196	492	86.2	24.5	61.6
3	176.58	12358	19.91	1614	502	1112	81.1	25.2	55.8
4	189.52	16961	29.33	2403	663	1740	81.9	22.6	59.3
5	247.01	13901	31.33	2716	974	1742	86.7	31.1	55.6
6	51.27	24638	11.53	1450	579	871	125.8	50.2	75.6
7	156.72	12175	17.41	1021	336	685	58.6	19.3	39.3
8	157.61	16848	24.23	1719	670	1049	70.9	27.6	43.3
9	57.09	9541	4.97	414	142	272	83.3	28.6	54.7
10	163.61	12177	18.18	1549	522	1027	85.2	28.7	56.5
Dist 5,8 & 9	461.70	14368	60.53	4849	1786	3063	80.1	29.5	50.6
Statewide	1433.82	13169	172.30	14062	4783	9279	81.6	27.8	53.9

[a] Length of four-lane divided expressways is counted separately for each direction of travel.
[b] During the period from 1997 to 2001, inclusive.

increase linearly with traffic volume, but this is not normally the case. As will be shown below, the relationship between accident frequency and traffic volume for two-lane highways is normally concave downward, such that accident frequency increases less rapidly than traffic volume.

Table 23 is comparable to Table 22 but includes only nonintersection accidents. Nonintersection accidents were found to include only 79 percent of total accidents for conventional two-lane highways and only 71 percent of total accidents for four-lane divided highways, but include 89 percent of total accidents for two-lane highways with passing lanes. The key accident rates from Table 23 for MoDOT Districts 5, 8, and 9 are summarized in Table 24. When only nonintersection accidents are considered, Table 24 shows that accident rates for two-lane highways with passing lanes are 20 percent lower than conventional two-lane highways for all accident severity levels combined, 19 percent lower for F&I accidents, and 21 percent lower for PDO accidents. It should be recognized, however, that this comparison of the safety performance of roadway types does not account for the effects of traffic volume. Specifically, the conventional two-lane highways had an average AADT of 5,165 veh/day, the two-lane highways with passing lanes had an average AADT of 7,388 veh/day, and the four-lane divided highways had an average AADT of 13,169 veh/day. Regression modeling was used to build safety prediction models based on traffic volumes that can be used to compensate for differences in traffic volume between the three roadway types.

Regression Relationships Between Accident Frequency and Traffic Volume

The data used to develop Tables 23 and 24 were used to develop regression relationships between accident frequency and ADT for each roadway type. These relationships, presented in Figure 24, were developed with negative binomial regression.

The regression models for the curves shown in Figure 24 for total nonintersection accidents, including all accident severity levels, are:

Conventional two-lane highways

$N_{tot} = \exp(-6.200)\ AADT^{0.805}\ L$ $\qquad R^2 = 0.495 \quad k=0.362$

Two-lane highways with passing lanes

$N_{tot} = \exp(-4.906)\ AADT^{0.638}\ L$ $\qquad R^2 = 0.532 \quad k=0.186$

Four-lane divided expressways (nonfreeways)

$N_{tot} = 2*\exp(-8.302)\ (AADT/2)^{0.992}\ L$ $\qquad R^2 = 0.458 \quad k=0.667$

Table 23 Nonintersection Accident Rates for Missouri Rural NHS Routes in Roadway Type and District

District	Total length (mi)[a]	Average two-way ADT[b] (veh/day)	Travel[b] (100 MVMT)	Number of accidents[b] Total	F&I	PDO	Accident rate (per 100 MVMT)[b] Total	F&I	PDO
Two-Lane Highways									
1	63.95	4238	4.95	405	165	240	81.9	33.4	48.5
2	149.80	4696	12.84	962	312	650	74.9	24.3	50.6
3	163.87	4782	14.30	1052	371	681	73.6	25.9	47.6
4	106.84	4816	9.39	1209	341	868	128.7	36.3	92.4
5	226.87	5223	21.62	2862	1023	1839	132.4	47.3	85.0
6	28.75	7384	3.87	552	203	349	142.5	52.4	90.1
7	127.62	6424	14.96	1262	454	808	84.4	30.3	54.0
8	128.10	7303	17.07	1359	500	859	79.6	29.3	50.3
9	223.44	4735	19.31	1543	567	976	79.9	29.4	50.5
10	245.44	4407	19.74	2180	755	1425	110.4	38.3	72.2
Dist 5,8 & 9	578.42	5495	58.01	5764	2090	3674	99.4	36.0	63.3
Statewide	1464.68	5165	138.06	13386	4691	8695	97.0	34.0	63.0
Two-Lane Highways with Added Passing Lanes									
5	7.88	8138	1.17	85	31	54	72.6	26.5	46.1
8	9.25	9787	1.65	119	46	73	72.0	27.8	44.2
9	8.92	4238	0.69	74	26	48	107.3	37.7	69.6
Dist 5,8 & 9	26.05	7388	3.51	278	103	175	79.1	29.3	49.8
Statewide	26.05	7388	3.51	278	103	175	79.1	29.3	49.8
Four-Lane Divided Expressways									
1	107.41	7572	7.42	376	144	232	50.7	19.4	31.3
2	127.02	6890	7.99	588	147	441	73.6	18.4	55.2
3	176.58	12358	19.91	1105	307	798	55.5	15.4	40.1
4	189.52	16961	29.33	1849	462	1387	63.0	15.8	47.3
5	247.01	13901	31.33	2185	737	1448	69.7	23.5	46.2
6	51.27	24638	11.53	941	348	593	81.6	30.2	51.4
7	156.72	12175	17.41	885	280	605	50.8	16.1	34.7
8	157.61	16848	24.23	800	293	507	33.0	12.1	20.9
9	57.09	9541	4.97	203	71	132	40.8	14.3	26.6
10	163.61	12177	18.18	1057	333	724	58.1	18.3	39.8
Dist 5,8 & 9	461.70	14368	60.53	3188	1101	2087	52.7	18.2	34.5
Statewide	1433.82	13169	172.30	9989	3122	6867	58.0	18.1	39.9

[a] Length of four-lane divided expressways is counted separately for each direction of travel.
[b] During the period from 1997 to 2001, inclusive.

Table 24. Comparison of Nonintersection Accident Rates on Missouri Rural NHS Routes in Districts 5, 8, and 9

Roadway type	Accident rate (per 100 MVMT)[a]		
	Total	F&I	PDO
Two-Lane Highways	99.4	36.0	63.3
Two-Lane Highways With Added Passing Lanes	79.1	29.3	49.8
Four-Lane Divided Expressways	52.7	18.2	34.5

[a] During the period from 1997 to 2001, inclusive.

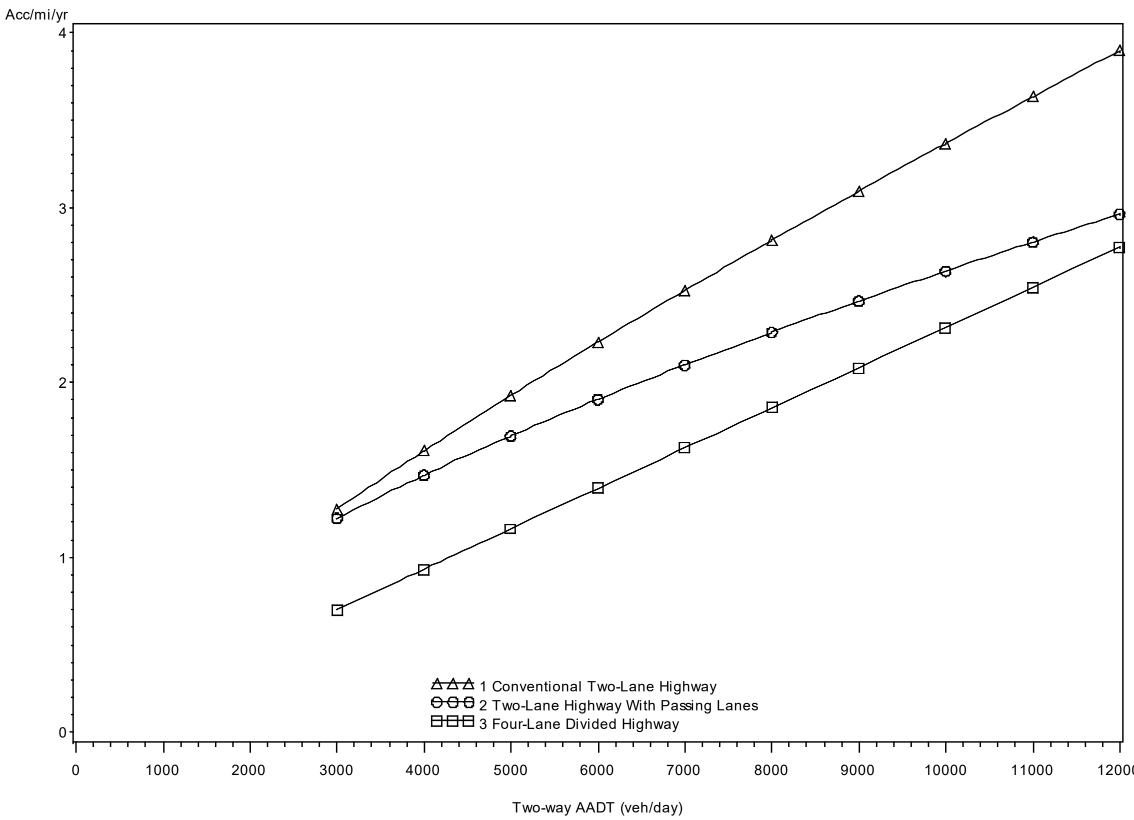


Figure 24. Regression Relationships Between Total Nonintersection Accident Frequency and Traffic Volume for Two-Lane and Four-Lane Roadways

where:

N_{tot} = Total number of accidents per mi per year

AADT = Two-way annual average daily traffic volume (veh/day)

The R^2 and k values shown for each regression model represent the goodness of fit for the models. R^2 is the conventional goodness of fit measure for regression models and represents the proportion of the variance in the overall accident frequencies that is explained by the model. The overdispersion parameter, k, represents the amount by which the variance of accident frequency exceeds the mean accident frequency; the negative binomial regression technique used to develop these models compensates for such overdispersion.

An attempt was made to develop regression models for F&I accidents comparable to the models for total accidents presented above. However, the models developed were not satisfactory, so this approach was not pursued.

Comparison of Accident Frequencies for Different Roadway Types Accounting for the Influence of Traffic Volumes

Figure 24, and the regression equations on which it is based, can be used to compare the difference in accident rate between the three roadway types for any specific traffic volume level. Specifically, Table 25 shows the differences in accident frequency per mi per year between roadway types for ADT levels from 5,000 to 12,000 veh/day. Table 26 shows the differences between accident frequency per mi per year expressed as a percentage difference.

It is apparent from Table 26 that installation of a passing lane on a two-lane rural highway has substantial safety benefits, although these benefits are less than those for conversion to a four-lane divided highway. The difference in total nonintersection accident frequency between two-lane highways with and without passing lanes on Missouri NHS routes ranges from 12 to 24 percent depending upon ADT, with higher differences in accident frequency at higher ADTs. This compares to an estimate of percent in total accident reduction from research at the national level (see Section 5 of this report).

The data in Tables 23 and 24 indicate that the percentage difference in nonintersection accident frequency between conventional two-lane highways and two-lane highways with passing lanes is nearly the same for all accident severity levels: 20 percent for total accidents, 19 percent for F&I accidents, and 21 percent for PDO accidents. Because these differences are so small, it is recommended that the percentage differences for all accident severity levels combined shown in Table 26 also be applied, where appropriate, to F&I and PDO accidents when considered separately.

Table 25. Differences Between Roadway Types in Accident Frequency Per Mile Per Year

Roadway type	Accident severity level	Accident frequency per mi per year — Two-way AADT (veh/day): 5000	6000	7000	8000	9000	10,000	11,000	12,000
Conventional Two-Lane Highway	All	1.93	2.23	2.53	2.81	3.09	3.37	3.64	3.90
Two-Lane Highway with Passing Lane	All	1.70	1.90	2.10	2.29	2.47	2.64	2.80	2.96
Four-Lane Divided Expressway	All	1.16	1.40	1.63	1.86	2.09	2.32	2.55	2.78

Table 26. Percentage Differences Between Roadway Types in Accident Frequency Per Mile Per Year

Roadway type	Accident severity level	Percentage difference in accident frequency per mi per year from a conventional two-lane highway — Two-way AADT (veh/day): 5000	6000	7000	8000	9000	10,000	11,000	12,000
Two-Lane Highway with Passing Lane	All	12.0	14.7	16.9	18.7	20.3	21.7	22.9	24.0
Four-Lane Divided Expressway	All	39.6	37.5	35.6	34.0	32.6	31.2	30.0	28.8

It should also be recognized that the safety differences for two-lane highways shown in Table 26 pertain to the portion of the highway over which passing lanes are installed, while the benefits shown for four-lane divided expressways pertain to the entire length of highway that is converted to a four-lane divided cross section. While the benefits of a four-lane divided highway are greater than those for passing lanes, the construction of a four-lane divided highway also costs substantially more.

Consideration was also given to making a comparison of accident experience before and after passing installation for as many of the existing passing lanes shown in Table 13 as possible and for passing lanes previously present on Missouri NHS routes that have since been replaced by four-lane divided highways. However, several of the existing passing lane sites were installed prior to the period for which accident and traffic volume data are currently available. Furthermore, it was found that, for periods prior to the mid-1990s, accident data for many of the existing passing lane sites are relatively sparse, suggesting underreporting of accident frequencies. Our assessment is that it would be difficult or impossible to conduct a valid before-after safety evaluation using the older accident data, so this effort was not pursued.

Summary

National research presented in Section 5 of this report suggests that passing lanes reduce accidents by 25 percent. However, varying results were found in state studies in Michigan and in various international studies that are also reported in Section 5.

Analysis of data for rural NHS routes in Missouri found lower differences in accident frequency between two-lane highways with and without passing lanes than suggested by the national research. However, the differences found are still substantial. Total accident frequencies on two-lane highways with passing lanes on Missouri NHS routes appear to be 12 to 24 percent lower than for conventional two-lane highways, with the larger differences being found for two-lane highways with higher traffic volumes. Regression models have been developed that permit the safety difference between a two-lane highway and a two-lane highway with a passing lane to be forecast for any specified traffic volume.

Section 10.
Criteria for Selecting Passing Locations in Missouri

This section presents criteria to determine where passing lanes could provide level of service and safety benefits on Missouri highways. Passing lanes are addressed in the AASHTO *Green Book*, but no formal criteria for their use have been established by AASHTO. Therefore, recommended criteria were developed as part of Task 3.

Two types of criteria are presented in this section: screening criteria and site-specific investigation criteria. *Screening criteria* can be used to screen an entire network of two-lane highways for potential candidates for passing lanes. Screening criteria include:

- Traffic volume (ADT or DHV)
- Available length of roadway for installation of a passing lane of optimal length
- Planned or programmed improvements at the site

The existing or expected safety performance of candidate sites might also be considered as a screening criterion.

Site-specific investigation criteria can be used to identify specific roadway sections where passing lanes may provide substantial level of service and safety benefits and that warrant further investigation in the field. Site-specific investigation criteria include:

- Truck volume or percent trucks (for climbing lanes)
- Operating speed, as influenced by horizontal and vertical alignment

Screening Criteria

The preliminary screening criteria for passing lanes are discussed below.

Traffic Volume

Traffic volume—existing and projected—is a key screening criterion that can be used to screen an entire network of two-lane highways for candidate locations for passing lanes. The capacity of a two-lane highway without passing lanes is 1,700 pc/h for each direction of travel and 3,200 pc/h for both directions of travel combined.(1) Most rural two-lane highways on Missouri NHS routes have traffic volumes substantially lower than these capacity values.

Section 4 of this report presents a detailed discussion of the traffic operational effectiveness of passing lanes. As noted in Section 4, two-lane highways with passing lanes can serve two-way design volumes up to 2,800 pc/h, and one-way design volumes up to 1,700 pc/h at LOS C, depending on the frequency of passing lanes provided. Passing lanes have been used in the United States and in Europe on two-lane highways with a wide range of traffic volumes. Passing lanes have been found to operate safely on two-lane highways in the United States with average daily traffic (ADT) volumes up to 20,000 veh/day.(7) In Europe, passing lanes have been used on roads with ADTs up to 25,000 veh/day and, in one case, 30,000 veh/day.(8) European experience suggests that the maximum desirable flow rate for a two-lane highway with passing lanes is 1,200 veh/h in one direction of travel.(8)

For screening for potential passing lane locations, the best tool is to list the candidate locations in order of descending ADT. The highest-volume sections on the list, especially those where projected traffic volumes exceed 20,000 veh/day or where a four-lane divided highway is anticipated before the design year, are not appropriate locations for provision of passing lanes except as an interim measure, prior to construction of the four-lane highway.

Passing lanes are very suitable for two-lane highways over a broad range of traffic volumes from 5,000 to 20,000 veh/day, where four-lane highway construction is not programmed or planned. Passing lanes lend themselves well to staged construction. Initially, a few passing lanes spaced at, say, 8-mi intervals in each direction of travel, may be provided. As traffic volumes grow, intermediate passing lanes may be added to reduce the passing lane interval to 4 mi in each direction of travel. Finally, passing lanes can be provided nearly continuously with passing lanes at intervals of 2 mi in each direction of travel. An advantage of staged construction is that the plan is less dependent on the accuracy of traffic volume forecasts. If a large increase in traffic volumes that has been forecast never materializes, the next stage of passing lane development need not be built. With a four-lane highway, the entire investment is made up front and that investment may or may not be borne out by future traffic volume increases.

Two-lane highways with existing and projected traffic volumes below 5,000 veh/day can generally provide acceptable traffic operational levels of service without passing lanes. With a K factor of 10 percent, a two-lane highway with an ADT of 5,000 veh/day would operate with a peak volume of 500 veh/h. Table 9 shows that such a road would operate at LOS B over a range of directional splits from 50/50 to 70/30. LOS B is generally considered an acceptable operational level of service for a two-lane highway.

In summary, site selection for passing lanes should focus on two-lane highways with existing and projected traffic volumes between 5,000 and 20,000 veh/day.

Available Length of Roadway

Another key criterion for screening an entire network of two-lane highways for candidate locations for passing lanes is the length of roadway section available for passing lanes (i.e., the length of roadway between major intersections and the edges of cities or towns). If the length of roadway available for placing passing lanes is too short, the operational and safety benefits of such a passing lane would be nominal.

Table 27 presents the range of optimal lengths for passing lanes in level and rolling terrain presented in the *Highway Capacity Manual*. Passing lanes shorter than the lengths shown in the table may not be able to satisfy all of the passing demand. Passing lanes longer than the lengths shown in the table may be inefficient because the downstream portion of the passing lane may be underutilized for passing. In most cases, it would be desirable to end the passing lane when the upper end of the optimal range is reached and introduce another passing lane downstream where passing demand has built up.

Passing lanes at the lower end of the range of optimal lengths are generally acceptable. Short passing lanes, with lengths of 0.25 mi or less, are not very effective in reducing traffic platooning. As the length of a passing lane increases above 1.0 mi, passing lanes generally provide diminishing operational benefits. Passing lanes over 1.0 mi in length are generally appropriate only on higher volume facilities, with flow rates over 700 veh/h.

Table 27. Optimal Lengths of Passing Lanes(1,3)

Directional flow rate (pc/h)	Optimal passing lane length (mi)
100	≤ 0.50
200	> 0.50-0.75
400	> 0.75-1.00
≥ 700	> 1.00-2.00

Based on the recommended values of length and spacing for passing lanes, a minimum available roadway length of 2.5 mi is recommended as a preliminary screening criterion. This criterion ensures that at least one 1.0-mi passing lane in each direction can be provided with space available for buffers between the passing lanes and at the end of the section.

Planned or Programmed Improvements at the Site

Determining the two-lane roadway sections where major improvements are already planned or programmed is another key screening criteria. For example, it would not be a wise economic decision to construct passing lanes on a two-lane highway that is programmed for widening to four lanes shortly thereafter. Therefore, those sites that are already programmed for four-lane highway improvements should be removed from consideration for passing lanes.

Existing or Expected Safety Performance

The existing or expected safety performance of a two-lane highway could also be considered as a screening criterion for candidate passing lane locations. Specifically, higher priorities might be assigned to locations at which the obscured nonintersection accident frequency exceeds the nonintersection accident frequency predicted by regression models presented in Section 9. At such locations, the safety effectiveness of providing a passing lane might be higher than predicted by the regression models. Rather than comparing the observed and predicted accident frequencies for candidate sites, it would also be possible to combine the values using the Empirical Bayes (EB) procedure to estimate the expected accident frequency for the site; the EB procedure provides a methodology to correct for *regression to the mean* resulting from high short-term accident rates.

Missouri NHS Roadway Locations That Meet Screening Criteria

The three screening criteria—traffic volume, available length of roadway, and programmed improvements—were applied to the statewide system of two-lane NHS roadways in Missouri to develop a list of locations that meet the preliminary criteria. Table 28 presents the list of two-lane NHS roadways in Missouri that meet the preliminary screening criteria presented above.

These sites have ADTs between 5,000 and 20,000 veh/day, lengths of 2.5 mi or more, and are not currently programmed for four-lane improvements. For convenience, the locations are arranged in descending order of current (2001) ADT. The list presented in Table 28 identifies specific NHS roadway sections that appear generally suited to passing lanes. The list does not represent explicit recommendations to MoDOT about where passing lanes should be constructed in the future. Such recommendations would require application of the selection criteria, followed by more detailed study. Indeed, for some of these roadways, especially those with higher ADTs, detailed study might lead to a recommendation of the site as a candidate for a four-lane highway. For some sites in the lower ADT range, the projected level of service might appear acceptable and a decision to stay with a conventional two-lane highway might be reached. However, for many sites in the center of the ADT range, a two-lane highway with passing lanes may be an appropriate design alternative. Detailed study of such sites is needed to indicate the level of service for various design alternatives and to choose the appropriate locations and spacing for passing lanes.

Site-Specific Investigation Criteria

The site-specific investigation criteria for identifying potential roadway sections suitable for passing lanes are discussed below.

Table 28. Rural NHS Roadway Locations in Missouri That Meet Screening Criteria

District	Route	County	Location	AADT	Continuous log mileage[a] Begin	End	Length
8	US 65	Taney	End of four lane to Arkansas state line	14800	305.31	313.57	8.3
8	US 65	Greene	End of four lane to beginning of four lane	13600	249.18	258.60	9.4
8	US 60	Christian/Greene	Lawrence Co Line to Republic	13100	61.98	70.64	8.7
7	MO 37	Barry	Monett to Purdy	11000	47.33	52.70	5.4
5	US 50	Cole	Centertown to beginning of four lane	9900	127.30	131.41	4.1
7	US 60	Lawrence	Aurora to Marionville	9800	54.53	59.90	5.4
5	US 65	Benton	Rte 52 south jct to Lincoln	8900	168.72	172.32	3.6
5	US 65	Benton	End of four lane to Rte 52 south jct	8800	162.73	167.02	4.3
9	US 63	Oregon	Koshkonong to beginning of four lane	8600	326.86	335.01	8.1
5	US 50	Moniteau/Cole	California to Centertown	8600	118.30	126.22	7.9
1	US 59	Buchanan	End of 50 mph zone to Kansas state line	8600	104.41	107.07	2.7
2	US 63	Macon	Rte DD to beginning of 45 mph zone	8600	57.49	60.05	2.6
8	US 65	Dallas/Greene	Rte 32 to beginning of four lane	8400	230.43	247.81	17.4
6	US 50	Franklin	Beaufort to Union	8400	206.30	215.47	9.2
5	US 50	Cole/Osage	End of four lane to Linn	8300	151.54	160.95	9.4
5	US 63	Osage	US 50 to Westphalia	8300	161.22	165.24	4.0
6	MO 100	Franklin/St. Louis	Gray Summit to Enter St. Louis area	8100	83.13	92.76	9.6
5	US 65	Benton	Lincoln to Rte 7 north jct	8000	173.33	183.95	10.6
8	MO 5	Laclede	Camden Co Line to beginning of four lane	7800	236.48	248.88	12.4
7	US 60	Barry/Lawrence	Monett to Aurora	7700	43.24	53.74	10.5
9	MO 8	Washington/St. Francois	Rtes O/U to Park Hills	7500	55.23	69.05	13.8
5	US 50	Gasconade/Franklin	Rosebud to Gerald	7500	194.04	196.65	2.6
9	US 63	Phelps	Rolla to Texas Co Line	7300	214.23	238.42	24.2
10	US 67	Butler	End of four lane to Arkansas state line	7300	184.10	199.51	15.4
4	MO 13	Lafayette	Higginsville to beginning of 45 mph zone	7300	96.11	99.80	3.7
3	US 24	Ralls/Marion	End of four lane to beginning of four lane	7200	181.04	192.32	11.3
2	US 36	Macon	End four lane to Shelby Co Line	7100	131.18	139.54	8.4
5	US 63	Maries/Phelps	Rte 68 to beginning of four lane	7000	199.34	208.96	9.6
4	MO 13	Lafayette/Johnson	End four lane to beginning of 45 mph zone	6900	100.45	115.10	14.6
7	US 54	Vernon/Cedar	Nevada to El Dorado Springs	6800	17.69	33.24	15.5
9	US 63	Howell/Oregon	Rte ZZ to Koshkonong	6500	312.49	326.18	13.7
7	MO 37	Barry	Purdy to beginning of 50 mph zone	6500	53.39	66.32	12.9
9	US 60	Howell/Shannon	Rte 17 west jct to Rte 19 west jct	6400	183.25	203.68	20.4
4	MO 92	Clay	Kearney to beginning of 45 mph zone	6400	32.82	38.60	5.8
5	US 50	Pettis/Morgan	Sedalia to Syracuse	6300	83.12	99.45	16.3
4	MO 92	Clay	Smithville to Kearney	6300	21.63	31.22	9.6
5	US 65	Benton	Rte 83 to Rte 7 south jct	6200	184.63	189.51	4.9

Table 28. Rural NHS Roadway Locations in Missouri That Meet Preliminary Screening Criteria (Continued)

District	Route	County	Location	AADT	Continuous log mileage[a] Begin	End	Length
4	MO 23	Johnson	US 50 to end of NHS route	6200	31.75	34.89	3.1
9	US 63	Texas	Houston to beginning of four lane	6000	261.29	277.00	15.7
5	US 50	Moniteau	Tipton to California	5900	106.60	116.59	10.0
3	US 54	Audrain	Mexico to Rte 19 south jct	5800	217.96	226.95	9.0
1	US 71	Andrew	Nodaway Co Line to beginning of four lane	5700	39.15	44.67	5.5
10	US 412	Dunklin	Arkansas St Line to Kennett	5600	0.00	20.40	20.4
7	US 54	Vernon	Kansas St Line to beginning of four lane	5500	0.00	9.70	9.7
1	US 59	Buchanan	St. Joseph to beginning of 50 mph zone	5400	90.12	103.97	13.9
5	US 63	Osage	Rte T to Freeburg	5400	167.93	175.33	7.4
5	US 50	Morgan/Moniteau	Syracuse to Tipton	5400	100.38	104.58	4.2
2	US 63	Schuyler	Queen City to Greentop	5400	13.25	16.98	3.7
9	US 63	Texas	Phelps Co Line to Rte 17 north jct	5300	238.42	259.62	21.2
4	MO 7	Henry	Clinton to Tightwad	5200	79.25	92.37	13.1
10	MO 32	St. Francois/Ste. Genevieve	Farmington to I-55	5100	257.66	279.26	21.6
10	US 67	Wayne/Butler	Greenville to beginning of four lane	5100	148.13	167.28	19.2
6	US 50	Franklin	Gerald to Leslie	5100	198.17	203.10	4.9

[a] Locations shown are continuous log miles in the southbound or eastbound direction even for passing lanes in the northbound or westbound direction.

Truck Volume

Truck volume is a key selection criteria that can be used to select specific roadway sections where passing lanes would provide the greatest level of service and safety benefits. Heavy vehicles—including trucks, recreational vehicles, and agricultural vehicles—can have a large effect on passing demand. Typically, the percentage of heavy vehicles on most two-lane roadways in the United States ranges between 10 and 20 percent. The need for providing more passing opportunities increases as the percentage of heavy vehicles increases.

On isolated steep grades, passing lanes may be strategically placed on the upgrades to serve as climbing lanes for trucks, recreational vehicles, and other slow-moving vehicles. The *Green Book* provides criteria to identify where truck climbing lanes are needed. Passing lanes may also be provided on steep downgrades to allow faster vehicles to pass slow-moving trucks.

The AASHTO *Green Book*(4) considers a climbing lane on a two-lane highway upgrade to be economically justified when the following criteria are met.

1. Upgrade traffic flow rate in excess of 200 veh/h
2. Upgrade truck flow rate in excess of 20 veh/h
3. One of the following conditions exist:
   - a 10-mph or greater speed reduction is expected for a typical truck
   - LOS E or F exists on the grade
   - a reduction of two or more levels of service is experienced when moving from the approach segment to the grade

The economic criteria indicate that a climbing lane may be provided when the criteria are met, not that a climbing lane must be provided.

When determining where to locate passing lanes within a specific roadway section, it is best to first identify any isolated steep grades that meet the *Green Book* criteria presented above; if warranted, climbing lanes for trucks and other slow-moving vehicles should be placed on those upgrades. Additional passing lanes can then be strategically placed at other locations, to obtain the overall desired level of service.

Operating Speed (as Influenced by Horizontal and Vertical Alignment)

Another selection criteria that can be used for selecting specific roadway sections where passing lanes would provide the greatest level of service and safety benefits is operating speed, as influenced by horizontal and vertical alignment. Reduced operating speeds may occur at sharp horizontal curves or on continuously rolling terrain, regardless of the traffic volumes on the facility. Such locations will not experience much operational improvement, in terms of operating speed, by the construction of passing lanes. For example, drivers that desire to pass slower moving vehicles would have difficulty doing so where their speeds were limited by sharp horizontal curvature. Thus, sites in terrain that substantially limit operating speed are not generally desirable as passing lane locations.

Operating speeds at candidate passing lane locations can be assessed through field visits to the candidate sites to observe traffic operations, through field studies of traffic speed, or from a formal speed prediction model like that used in the design consistency model of FHWA's Interactive Highway Safety Design Module (IHSDM). Passing lanes are appropriate for two-lane highway locations with 85th percentile speeds over 45 mph and are most suitable for locations with 85th percentile speeds over 55 mph.

Detailed Design

The screening criteria presented above are used to identify sites that have potential as candidate sites for passing lanes. The site-specific investigation criteria are then applied to the candidate sites to make a final assessment of which portions of those sites are most suitable for passing lanes. The next step involves detailed design of the passing lanes, including the selection of appropriate locations for passing lanes. Detailed design of passing lanes should consider the following:

- Passing lane locations
- Lane width
- Shoulder width
- Lane addition taper design
- Lane drop taper design
- Intersection treatments
- Signing and marking of passing lanes

Section 3 of this report presents location criteria for passing lanes, Section 6 addresses the geometric design of passing lanes, and Section 7 addresses effective signing and marking of passing lanes. Specific recommendations concerning criteria for passing lane design, signing, and marking, for consideration by MoDOT in development of future policies on the use of passing lanes in Missouri, are presented in Section 12 of this report.

Section 11.
Case Studies

This section presents the results of five case studies. Each case study involved the selection of specific passing lane locations along an existing two-lane highway section in Missouri. Traffic operational and safety analyses were then performed for that roadway section. The case studies illustrate how the process of selecting passing lane locations can be incorporated in the project development process.

Case Study Sites

The list of Missouri NHS roadway locations meeting the preliminary screening criteria, as presented in Table 28, does not identify the specific locations within those sections where passing lanes should be placed. The selection of specific passing lane locations within an appropriate roadway section requires more detailed study. Such detailed studies to determine specific passing lane locations were conducted for five case study sites. The case study sites were selected in consultation with MoDOT and include two-lane highways with a range of traffic volume levels in several MoDOT districts. The selected two-lane highway corridors include:

District	County	Route	Corridor limits
3	Ralls/Audrain	US 54/MO 19	New London to Mexico
4	Lafayette/Johnson/Henry	MO 13	US 24 to MO 7
7	Barry	MO 37	Monett to the Arkansas state line
8	Laclede	MO 5	Camden County line to Lebanon
10	Madison/Wayne	US 67	Millcreek to Greenville

Within each corridor, MRI selected an appropriate case study site, consisting of a relatively uniform roadway section suitable for passing lanes. Table 29 presents the section limits for each of the five case study sections.

Table 29. Case Study Sections Included in the Analysis

			Continuous log mile[a] (approximate)		
District	County	Route	From	To	Length (mi)
3	Audrain	US 54	218.0	227.0	9.0
4	Lafayette/Johnson	MO 13	101.2	109.2	8.0
7	Barry	MO 37	47.3	52.7	5.4
8	Laclede	MO 5	237.4	248.9	11.5
10	Wayne	US 67	132.7	142.8	10.1

[a] Southbound or eastbound direction.

Each roadway section has a consistent speed limit for a sufficient distance to accommodate at least two passing lanes and does not include any cities or towns.

MRI developed one or two alternative configurations for passing lanes within each case study site and performed a level of service and safety analysis of those alternatives, in comparison to the existing two-lane highway and to a four-lane highway divided alternative. The passing lane alternatives for each study included a maximum passing lane configuration for which passing lanes extended along as much of the case study site as practical, with the exception of approaches to major intersections and areas with substantial roadside development. In most of the case studies, an intermediate passing lane configuration, with fewer passing lanes than the maximum passing lane configuration, was evaluated. The intermediate passing lane configuration could be considered as an initial step in stage construction toward the maximum passing lane configuration; the intermediate passing lane configuration might provide an appropriate level of service for tens years until traffic volume growth indicated a need for the maximum passing lane configuration. Each case study is presented in detail below.

District 3 Case Study: US 54 in Audrain County

A case study was conducted for a 9.0-mi section of US 54 in Audrain County. The following discussion addresses the lane configurations that were evaluated, the passing lane locations selected, traffic volumes and characteristics, and the traffic operational analysis results.

Lane Configuration

A traffic operational analysis for the US 54 case study was conducted for the following alternatives:

- *Existing configuration*—two-lane roadway with no passing lanes
- *Intermediate passing lane configuration*—two-lane roadway with two passing lanes in each direction
- *Maximum passing lane configuration*—two-lane roadway with three passing lanes in each direction
- *Four-lane divided highway*—two lanes in each direction with a median throughout the entire project length

The US 54 roadway section selected for this case study includes two major intersections, Routes A and B, which were considered in the selection of passing lane locations. Passing lanes were located at least 0.25 mi from each intersection.

Table 30 summarizes the cross sections along the US 54 roadway section for the intermediate passing lane configuration. The roadway section is 9.00 mi in length and includes two eastbound and two westbound passing lanes. In this configuration, nearly 24 percent of the total roadway length includes passing lanes in each direction of travel. The intermediate passing lane configuration represents a possible first step in staged construction. Initially, a few passing lanes are provided; as traffic volumes grow, additional passing lanes may be added. Finally, passing lanes can be provided nearly continuously, as represented by the maximum passing lane configuration.

Table 30. Summary of Roadway Lengths by Lane Configuration—Intermediate Passing Lane Configuration (US 54 Case Study)

Lane configuration	Continuous log mile[a] (approximate) From	To	Length (mi)
EB passing lane	218.00	219.10	1.10
Two-lane undivided	219.10	219.60	0.50
WB passing lane	219.60	220.70	1.10
Two-lane undivided	220.70	224.40	3.70
EB passing lane	224.40	225.40	1.00
Two-lane undivided	225.40	225.90	0.50
WB passing lane	225.90	227.00	1.10
		Total	9.00

[a] Locations shown are continuous log miles in the southbound or eastbound direction even for passing lanes in the northbound or westbound direction.

Table 31 summarizes the cross sections along the US 54 roadway section for the maximum passing lane configuration. The roadway section is 9.00 mi in length and includes three eastbound and three westbound passing lanes. In this configuration, nearly 40 percent of the total roadway length includes passing lanes in each direction of travel.

Table 31. Summary of Roadway Lengths by Lane Configuration—Maximum Passing Lane Configuration (US 54 Case Study)

Lane configuration	Continuous log mile[a] (approximate) From	To	Length (mi)
EB passing lane	218.00	219.10	1.10
Two-lane undivided	219.10	219.60	0.50
WB passing lane	219.60	220.70	1.10
Two-lane undivided	220.70	221.30	0.60
EB passing lane	221.30	222.80	1.50
Two-lane undivided	222.80	223.35	0.55
WB passing lane	223.35	224.40	1.05
EB passing lane	224.40	225.40	1.00
Two-lane undivided	225.40	225.90	0.50
WB passing lane	225.90	227.00	1.10
		Total	9.00

[a] Locations shown are continuous log miles in the southbound or eastbound direction even for passing lanes in the northbound or westbound direction.

The estimated construction costs for the three improvement alternatives are $2.3 million for the intermediate passing lane configuration, $3.7 million for the maximum passing lane configuration, and $15.7 million for a four-lane divided highway.

Traffic Volumes and Characteristics

The traffic operational analysis of the US 54 roadway section was based on current-year (2003) traffic volumes and on projected traffic volumes for 2023. Current-year traffic volumes were based on data provided by MoDOT staff. Projected traffic volumes were estimated using a growth rate of 2.3 percent, based on historical traffic volume data for this roadway section. The current-year hourly volume used in the analysis was 560 veh/h, which represents 10 percent of the 2003 AADT of about 5,600 veh/day. The 20-year projected hourly volume used in the analysis was 880 veh/h, which represents 10 percent of the estimated 2023 AADT of about 8,800 veh/day.

The traffic composition consisted of 16 percent heavy vehicles (11 percent trucks and five percent recreational vehicles). The traffic operational analysis was performed for a 60/40 directional split. In one set of simulation runs, the EB direction of travel carried 60 percent of the traffic; in another set of simulation runs, the WB direction of travel carried 60 percent of the traffic.

Traffic Operational Analysis Results

Table 32 presents the results of the traffic operational analysis of the US 54 roadway section conducted using the TWOPAS model. With the existing configuration of no passing lanes, the US 54 roadway section currently operates around LOS B or C, depending on the directional split. When the eastbound lane carries 60 percent of the traffic, the roadway section operates at a LOS C. When the westbound lane carries 60 percent of the traffic, the roadway section operates at a LOS B. At projected 2023 traffic volumes, the existing configuration would operate at a LOS C.

With the intermediate passing lane configuration, the US 54 roadway section would currently operate at a LOS B, but very close to a LOS A. By 2023, this configuration would still be operating at a LOS B.

With the maximum passing lane configuration, the US 54 roadway section would currently operate at a LOS A. By 2023, this configuration would operate at a LOS B, but very close to a LOS A.

The four-lane divided highway configuration would operate at LOS A in years 2003 and 2023.

Traffic Safety Analysis Results

Table 33 presents a summary of the traffic safety analysis results for the US 54 case study. The table shows that the anticipated reduction in total nonintersection accident frequency for the intermediate passing lane, maximum passing lane, and four-lane divided highway configurations are 7, 10, and 44 percent respectively. The table also shows that, from a safety standpoint, the passing lane alternatives have about the same cost effectiveness as the four-lane divided highway configuration.

Table 32. Summary of Traffic Operational Analysis Results for US 54 Case Study

Lane configuration	Hourly volume (veh/h)		Percent time spent following	Average travel speed (mph)	LOS
	EB	WB			
2003					
Existing configuration (without passing lanes)	336	224	53.5	57.6	C
	224	336	43.3	57.6	B
Intermediate passing lane configuration	336	224	36.4	58.8	B
	224	336	35.1	58.9	B
Maximum passing lane configuration	336	224	26.3	59.6	A
	224	336	24.7	59.8	A
2023					
Existing configuration (without passing lanes)	528	352	61.2	56.8	C
	352	528	61.7	56.9	C
Intermediate passing lane configuration	528	352	45.7	58.0	B
	352	528	45.4	58.1	B
Maximum passing lane configuration	528	352	35.3	58.8	B
	352	528	35.8	58.8	B

The 44-percent reduction in accident frequency for the four-lane divided highway configuration shown in Table 33 represents an equal reduction in all accident severity levels over the entire length of the case study site. The reductions in accident frequency for the intermediate and maximum passing lane configurations are based on a reduction in accident frequency of 14 percent for all accident severity levels in the portions of the case study site where passing lanes are provided (see Tables 30 and 31). This percentage reduction was determined from Table 26 and the accompanying regression equations for the current AADT of the case study site. The percentage reductions for specific accident frequency levels shown in Table 33 for the alternative passing lane configurations vary because the accident severity distribution in the improved portions of the site differ from the accident severity distribution for the site as a whole.

District 4 Case Study: MO 13 in Lafayette/Johnson Counties

A case study was conducted for an 8.0-mi section of MO 13 in Lafayette and Johnson Counties. The following discussion addresses the lane configurations that were evaluated, the passing lane locations selected, traffic volumes and characteristics, and the traffic operational analysis results.

Lane Configuration

A traffic operational analysis for the MO 13 case study was conducted for the following alternatives:

- *Existing configuration*—two-lane roadway with no passing lanes
- *Intermediate passing lane configuration*—two-lane roadway with one passing lane in each direction
- *Maximum passing lane configuration*—two-lane roadway with two passing lanes in each direction
- *Four-lane divided highway*—two lanes in each direction with a median throughout the entire project length

Table 34 summarizes the cross sections along the MO 13 roadway section for the intermediate passing lane configuration. The roadway section is 8.00 mi in length and includes one northbound and one southbound passing lane. In this configuration, about 18 percent of the total roadway length includes passing lanes in each direction of travel.

Table 33. Summary of Traffic Safety Analysis Results for US 54 Case Study

Lane configuration	Section length (mi)	Length of added lanes (mi)	Percent reduction in nonintersection accident frequency			Cost effectiveness (expenditures per accident reduced over 20-year period)
			F&I	PDO	Total	
Intermediate passing lanes	9.0	4.3[a]	6	7	7	$17,100
Maximum passing lanes	9.0	6.9[a]	9	10	10	$18,500
Four-lane divided	9.0	18.0[b]	44	44	44	$17,400

[a] One direction of travel only.
[b] Both directions of travel for entire section length.

Table 34. Summary of Roadway Lengths by Lane Configuration—Intermediate Passing Lane Configuration (MO 13 Case Study)

Lane configuration	Continuous log mile[a] (approximate) From	To	Length (mi)
Two-lane undivided	101.20	105.05	3.85
SB passing lane	105.05	106.50	1.45
Two-lane undivided	106.50	106.90	0.40
NB passing lane	106.90	108.40	1.50
Two-lane undivided	108.40	109.20	0.80
		Total	8.00

[a] Locations shown are continuous log miles in the southbound or eastbound direction even for passing lanes in the northbound or westbound direction.

Table 35 summarizes the cross sections along the MO 13 roadway section for the maximum passing lane configuration. The roadway section is 8.00 mi in length and includes two northbound and two southbound passing lanes. In this configuration, nearly 30 percent of the total roadway length includes passing lanes in each direction of travel.

Table 35. Summary of Roadway Lengths by Lane Configuration—Maximum Passing Lane Configuration (MO 13 Case Study)

Lane configuration	Continuous log mile[a] (approximate) From	To	Length (mi)
Two-lane undivided	101.20	102.20	1.00
SB passing lane	102.20	103.10	0.90
Two-lane undivided	103.10	103.55	0.45
NB passing lane	103.55	104.45	0.90
Two-lane undivided	104.45	105.05	0.60
SB passing lane	105.05	106.50	1.45
Two-lane undivided	106.50	106.90	0.40
NB passing lane	106.90	108.40	1.50
Two-lane undivided	108.40	109.20	0.80
		Total	8.00

[a] Locations shown are continuous log miles in the southbound or eastbound direction even for passing lanes in the northbound or westbound direction.

The estimated construction costs for the three improvement alternatives are $1.6 million for the intermediate passing lane configuration, $2.5 million for the maximum passing lane configuration, and $14.0 million for the four-lane divided highway.

Traffic Volumes and Characteristics

The traffic operational analysis of the MO 13 roadway section was based on current-year (2003) traffic volumes and on projected traffic volumes for 2023. Current-year traffic volumes were based on data provided by MoDOT staff. Projected traffic volumes were estimated using a growth rate of 2.2 percent, based on historical traffic volume data for this roadway section. The current-year hourly volume used in the analysis was 755 veh/h, which represents 10 percent of the 2003 AADT of about 7,550 veh/day. The 20-year projected hourly volume used in the analysis was 1,167 veh/h, which represents 10 percent of the estimated 2023 AADT of about 11,670 veh/day.

The traffic composition consisted of 16 percent heavy vehicles (11 percent trucks and five percent recreational vehicles). The traffic operational analysis was performed for a 60/40 directional split. In one set of simulation runs, the NB direction of travel carried 60 percent of the traffic; in another set of simulation runs, the SB direction of travel carried 60 percent of the traffic.

Traffic Operational Analysis Results

Table 36 presents the results of the traffic operational analysis of the MO 13 roadway section. With the existing configuration of no passing lanes, the MO 13 roadway section currently operates at a LOS C. At projected 2023 traffic volumes, the existing configuration would operate at a LOS D.

With the intermediate passing lane configuration, the MO 13 roadway section would currently operate at a LOS B. By 2023, this configuration would operate at a LOS C.

With the maximum passing lane configuration, the MO 13 roadway section would currently operate at a LOS A. By 2023, this configuration would operate at a LOS B.

The four-lane divided highway configuration would operate at LOS A in years 2003 and 2023.

Traffic Safety Analysis Results

Table 37 presents a summary of the traffic safety analysis results for the MO 13 case study. The table shows that the anticipated reduction in total nonintersection accident frequency for the intermediate passing lane, maximum passing lane, and four-lane divided highway configurations are 6, 7, and 42 percent, respectively. The table shows that, from a safety standpoint, the passing lane alternatives are slightly more cost effective than the four-lane divided highway configuration.

Table 36. Summary of Traffic Operational Analysis Results for MO 13 Case Study

Lane configuration	Hourly volume (veh/h) NB	Hourly volume (veh/h) SB	Percent time spent following	Average travel speed (mph)	LOS
2003					
Existing configuration (without passing lanes)	453	302	57.4	56.7	C
	302	453	56.7	56.6	C
Intermediate passing lane configuration	453	302	44.2	57.7	B
	302	453	43.0	57.7	B
Maximum passing lane configuration	453	302	34.4	58.6	A
	302	453	33.7	58.4	A
2023					
Existing configuration (without passing lanes)	700	467	65.7	55.8	D
	467	700	65.3	55.8	D
Intermediate passing lane configuration	700	467	53.7	56.8	C
	467	700	53.4	56.7	C
Maximum passing lane configuration	700	467	44.4	57.5	B
	467	700	44.6	57.4	B

Table 37. Summary of Traffic Safety Analysis Results for MO 13 Case Study

Lane configuration	Section length (mi)	Length of added lanes (mi)	Percent reduction in nonintersection accident frequency F&I	PDO	Total	Cost effectiveness (expenditures per accident reduced over 20-year period)
Intermediate passing lanes	8.0	3.0[a]	5	6	6	$12,800
Maximum passing lanes	8.0	4.8[a]	6	8	7	$10,200
Four-lane divided	8.0	16.0[b]	42	42	42	$15,600

[a] One direction of travel only.
[b] Both directions of travel for entire section length.

District 7: MO 37 in Barry County

A case study was conducted for a 5.4-mi section of MO 37 in Barry County. The following discussion addresses the lane configurations that were evaluated, the passing lane locations selected, traffic volumes and characteristics, and the traffic operational analysis results.

Lane Configuration

A traffic operational analysis for the MO 37 case study was conducted for the following alternatives:

- *Existing configuration*—two-lane roadway with no passing lanes
- *Maximum passing lane configuration*—two-lane roadway with three passing lanes in each direction
- *Four-lane divided highway*—two lanes in each direction with a median throughout the entire project length

The MO 37 roadway section selected for this case study included one major intersection, Route BB, that was considered in the selection of passing lane locations. Passing lanes were located at least 0.25 mi from this intersection.

Table 38 summarizes the cross sections along the MO 37 roadway section for the maximum passing lane configuration. The roadway section is 5.40 mi in length and includes two northbound and two southbound passing lanes. In this configuration, 29 percent of the total roadway length includes passing lanes in each direction of travel. No intermediate passing lane configuration was considered for this site because, based on the traffic operational analysis results shown in Table 39, any intermediate passing lane configuration would be likely to operate at the same level of service as the existing highway. Thus, this site is not a good candidate for staged construction of passing lanes; any passing lane project designed for this site should include as many passing lanes as practical in the initial design.

Table 38. Summary of Roadway Lengths by Lane Configuration—Maximum Passing Lane Configuration (MO 37 Case Study)

Lane configuration	Continuous log mile[a] (approximate) From	To	Length (mi)
SB passing lane	47.30	47.95	0.65
Two-lane undivided	47.95	48.35	0.40
NB passing lane	48.35	49.00	0.65
Two-lane undivided	49.00	49.50	0.50
SB passing lane	49.50	50.40	0.90
Two-lane undivided	50.40	50.76	0.36
NB passing lane	50.76	51.66	0.90
Two-lane undivided	51.66	52.70	1.04
		Total	5.40

[a] Locations shown are continuous log miles in the southbound or eastbound direction even for passing lanes in the northbound or westbound direction.

The estimated construction costs for the two alternatives are $3.1 million for the maximum passing lane configuration and $5.4 million for the four-lane divided highway.

Table 39. Summary of Traffic Operational Analysis Results for MO 37 Case Study

Lane configuration	Hourly volume (veh/h) NB	SB	Percent time spent following	Average travel speed (mph)	LOS
2003					
Existing configuration (without passing lanes)	717	478	62.5	56.1	C
	478	717	62.2	56.1	C
Maximum passing lane configuration	717	478	44.2	57.4	B
	478	717	42.9	57.6	B

Traffic Volumes and Characteristics

The traffic operational analysis of the MO 37 roadway section was based on current-year (2003) traffic volumes. Historical traffic volume data indicated that traffic volumes on the MO 37 roadway section had stabilized. Therefore, the 2003 analysis results may also provide a reasonable estimate of the level of service in 2023. Current-year traffic volumes were based on data provided by MoDOT staff. The current-year hourly volume used in the analysis was 1,195 veh/h, which represents 10 percent of the 2003 AADT of about 11,950 veh/day.

The traffic composition consisted of 16 percent heavy vehicles (11 percent trucks and five percent recreational vehicles). The traffic operational analysis was performed for a 60/40 directional split. In one set of simulation runs, the NB direction of travel carried 60 percent of the traffic; in another set of simulation runs, the SB direction of travel carried 60 percent of the traffic.

Traffic Operational Analysis Results

Table 39 presents the results of the traffic operational analysis of the MO 37 roadway section. With the existing configuration of no passing lanes, the MO 37 roadway section currently operates at a LOS C. With the maximum passing lane configuration, the MO 37 roadway section would currently operate at a LOS B.

The four-lane divided highway configuration would currently operate at LOS A.

Traffic Safety Analysis Results

Table 40 presents a summary of the traffic safety analysis results for the MO 37 case study. The table shows that the anticipated reduction in total nonintersection accident frequency for the maximum passing lane and four-lane divided highway configurations are 12 and 38 percent, respectively. The table shows that, from a safety standpoint, because of the relatively high traffic volume at this site, the four-lane divided highway configuration is more cost effective than the passing lane configuration.

District 8: MO 5 in Laclede County

A case study was conducted for an 11.5-mi section of MO 5 in Laclede County. The following discussion addresses the lane configurations that were evaluated, the passing lane locations selected, traffic volumes and characteristics, and the traffic operational analysis results.

Lane Configuration

A traffic operational analysis for the MO 5 case study was conducted for the following alternatives:

- *Existing configuration* – two-lane roadway with no passing lanes
- *Intermediate passing lane configuration* – two-lane roadway with two passing lanes in each direction

Table 40. Summary of Traffic Safety Analysis Results for MO 37 Case Study

Lane configuration	Section length (mi)	Length of added lanes (mi)	Percent reduction in nonintersection accident frequency			Cost effectiveness (expenditures per accident reduced over 20-year period)
			F&I	PDO	Total	
Intermediate passing lanes	5.4	3.1[a]	9	14	12	$13,500
Four-lane divided highway	5.4	10.8[b]	38	38	38	$7,400

[a] One direction of travel only.
[b] Both directions of travel for entire section length.

- *Maximum passing lane configuration* – two-lane roadway with three passing lanes in each direction
- *Four-lane divided highway*—two lanes in each direction with a median throughout the entire project length

The MO 5 roadway section selected for this case study included one major intersection, Route BB, that was considered in the selection of passing lane locations. Passing lanes were located at least 0.25 mi from this intersection. Left-turn lanes are currently present at the intersection of MO 5 with Route E and may be considered in the future at the intersection of Houston Road. Provision of left-turn lanes with the proposed passing lanes at these locations should be considered.

Table 41 summarizes the cross sections along the MO 5 roadway section for the intermediate passing lane configuration. The roadway section is 11.50 mi in length and includes two northbound and two southbound passing lanes. In this configuration, 24 percent of the total roadway length includes passing lanes in each direction of travel.

Table 41. Summary of Roadway Lengths by Lane Configuration— Intermediate Passing Lane Configuration (MO 5 Case Study)

Lane configuration	Continuous log mile[a] (approximate) From	To	Length (mi)
SB passing lane	237.40	238.85	1.45
Two-lane undivided	238.85	239.25	0.40
NB passing lane	239.25	240.70	1.45
Two-lane undivided	240.70	244.65	3.95
SB passing lane	244.65	245.95	1.30
Two-lane undivided	245.95	246.35	0.40
NB passing lane	246.35	247.65	1.30
Two-lane undivided	247.65	248.90	1.25
		Total	11.50

[a] Locations shown are continuous log miles in the southbound or eastbound direction even for passing lanes in the northbound or westbound direction.

Table 42 summarizes the cross sections along the MO 5 roadway section for the maximum passing lane configuration. The roadway section is 11.50 mi in length and includes three northbound and three southbound passing lanes. In this configuration, 36 percent of the total roadway length includes passing lanes in each direction of travel.

Table 42. Summary of Roadway Lengths by Lane Configuration—Maximum Passing Lane Configuration (MO 5 Case Study)

Lane configuration	Continuous log mile[a] (approximate) From	To	Length (mi)
SB passing lane	237.40	238.85	1.45
Two-lane undivided	238.85	239.25	0.40
NB passing lane	239.25	240.70	1.45
SB passing lane	240.70	242.15	1.45
Two-lane undivided	242.15	242.55	0.40
NB passing lane	242.55	244.00	1.45
Two-lane undivided	244.00	244.65	0.65
SB passing lane	244.65	245.95	1.30
Two-lane undivided	245.95	246.35	0.40
NB passing lane	246.35	247.65	1.30
Two-lane undivided	247.65	248.90	1.25
		Total	11.50

[a] Locations shown are continuous log miles in the southbound or eastbound direction even for passing lanes in the northbound or westbound direction.

The estimated construction costs for the improvement alternatives are $2.9 million for the intermediate passing lane configuration, $4.4 million for the maximum passing lane configurations, and $20.0 million for the four-lane divided highway configurations.

Traffic Volumes and Characteristics

The traffic operational analysis of the MO 5 roadway section was based on current-year (2003) traffic volumes. Historical traffic volume data indicated that traffic volumes on the MO 5 roadway section had stabilized. Therefore, the 2003 analysis results may also provide a reasonable estimate of the level of service for 2023. Current-year traffic volumes were based on data provided by MoDOT staff. Traffic volumes south of Route BB were substantially higher than traffic volumes north of Route BB. Therefore, a range of traffic volumes was used in the analysis. The current-year hourly volumes ranged from 677 to 977 veh/h, which represents 10 percent of the 2003 AADT (6,770 veh/day—north of Route BB; 9,770 veh/day—south of Route BB).

The traffic composition consisted of 20 percent heavy vehicles (15 percent trucks and five percent recreational vehicles). The traffic operational analysis was performed for a 60/40 directional split. In one set of simulation runs, the NB direction of travel carried 60 percent of the traffic; in another set of simulation runs, the SB direction of travel carried 60 percent of the traffic.

Traffic Operational Analysis Results

Table 43 presents the results of the traffic operational analysis of the MO 5 roadway section. With the existing configuration of no passing lanes, the MO 5 roadway section currently operates at a LOS C. With the intermediate passing lane configuration, the MO 5 roadway section would currently operate at a LOS B. With the maximum passing lane configuration, the MO 5 roadway section would currently operate at a LOS A.

The four-lane divided highway configuration would currently operate at LOS A.

Table 43. Summary of Traffic Operational Analysis Results for MO 5 Case Study

Lane configuration	Hourly volume (veh/h)		Percent time spent following	Average travel speed (mph)	LOS
	NB	SB			
2003					
Existing configuration (without passing lanes)	406-586	271-391	54.2	57.0	C
	271-391	406-586	53.5	56.9	C
Intermediate passing lane configuration	406-586	271-391	40.7	58.0	B
	271-391	406-586	39.9	58.0	B
Maximum passing lane configuration	406-586	271-391	33.0	58.6	A
	271-391	406-586	31.5	58.7	A

Traffic Safety Analysis Results

Table 44 presents a summary of the traffic safety analysis results for the MO 5 case study. The table shows that the anticipated reduction in total nonintersection accident frequency for the intermediate passing lane, maximum passing lane, and four-lane divided highway configurations are 8, 12, and 42 percent, respectively. The table shows that, from a safety standpoint, the passing lane alternatives are more cost effective than the four-lane divided highway configuration.

District 10: US 67 in Wayne County

A case study was conducted for a 10.1-mi section of US 67 in Wayne County. The following discussion addresses the lane configurations that were evaluated, the passing lane locations selected, traffic volumes and characteristics, and the traffic operational analysis results.

Table 44. Summary of Traffic Safety Analysis Results for MO 5 Case Study

Lane configuration	Section length (mi)	Length of added lanes (mi)	Percent reduction in nonintersection accident frequency			Cost effectiveness (expenditures per accident reduced over 20-year period)
			F&I	PDO	Total	
Intermediate passing lanes	11.4	5.4[a]	9	8	8	$10,500
Maximum passing lanes	11.4	8.3[a]	12	12	12	$11,300
Four-lane divided highway	11.4	22.8[b]	42	42	42	$14,800

[a] One direction of travel only.
[b] Both directions of travel for entire section length.

Lane Configuration

A traffic operational analysis for the US 67 case study was conducted for the following alternatives:

- *Existing configuration* – two-lane roadway with no passing lanes
- *Intermediate passing lane configuration* – two-lane roadway with two passing lanes in each direction
- *Maximum passing lane configuration* – two-lane roadway with three passing lanes in each direction
- *Four-lane divided highway*—two lanes in each direction with a median throughout the entire project length

The US 67 roadway section selected for this case study included two major intersections, Routes EE and K, and three bridges, all of which were considered in the selection of passing lane locations. Passing lanes were located at least 0.25 mi from each intersection and bridge.

Table 45 summarizes the cross sections along the US 67 roadway section for the intermediate passing lane configuration. The roadway section is 10.10 mi in length and includes two northbound and two southbound passing lanes. In this configuration, 22 to 24 percent of the total roadway length includes passing lanes in each direction of travel.

Table 45. Summary of Roadway Lengths by Lane Configuration—Intermediate Passing Lane Configuration (US 67 Case Study)

Lane configuration	Continuous log mile[a] (approximate) From	To	Length (mi)
SB passing lane	132.70	133.25	0.55
Two-lane undivided	133.25	133.75	0.50
NB passing lane	133.75	134.25	0.50
Two-lane undivided	134.25	138.30	4.05
SB passing lane	138.30	140.15	1.85
Two-lane undivided	140.15	140.65	0.50
NB passing lane	140.65	142.35	1.70
Two-lane undivided	142.35	142.80	0.45
		Total	10.10

[a] Locations shown are continuous log miles in the southbound or eastbound direction even for passing lanes in the northbound or westbound direction.

Table 46 summarizes the cross sections along the US 67 roadway section for the maximum passing lane configuration. The roadway section is 10.10 mi in length and includes three northbound and three southbound passing lanes. In this configuration, about 35 percent of the total roadway length includes passing lanes in each direction of travel.

Table 46. Summary of Roadway Lengths by Lane Configuration—Maximum Passing Lane Configuration (US 67 Case Study)

Lane configuration	Continuous log mile[a] (approximate) From	To	Length (mi)
SB passing lane	132.70	133.25	0.55
Two-lane undivided	133.25	133.75	0.50
NB passing lane	133.75	134.25	0.50
Two-lane undivided	134.25	134.85	0.60
SB passing lane	134.85	136.05	1.20
Two-lane undivided	136.05	136.45	0.40
NB passing lane	136.45	137.70	1.25
Two-lane undivided	137.70	138.30	0.60
SB passing lane	138.30	140.15	1.85
Two-lane undivided	140.15	140.65	0.50
NB passing lane	140.65	142.35	1.70
Two-lane undivided	142.35	142.80	0.45
		Total	10.10

[a] Locations shown are continuous log miles in the southbound or eastbound direction even for passing lanes in the northbound or westbound direction.

The estimated construction costs for the three improvement alternatives are $2.5 million for the intermediate passing lane configuration, $3.7 million for the maximum passing lane configuration, and $17.7 million for the four-lane divided highway configuration.

Traffic Volumes and Characteristics

The traffic operational analysis of the US 67 roadway section was based on current-year (2003) traffic volumes. Historical traffic volume data indicated that traffic volumes on the US 67 roadway section had stabilized. Therefore, the 2003 analysis results may also provide a reasonable estimate of the level of service for 2023. Current-year traffic volumes were based on data provided by MoDOT staff. The current-year hourly volume used in the analysis was 428 veh/h, which represents 10 percent of the 2003 AADT of about 4,280 veh/day.

The traffic composition consisted of 22 percent heavy vehicles (17 percent trucks and five percent recreational vehicles). The traffic operational analysis was performed for a 60/40 directional split. In one set of simulation runs, the NB direction of travel carried 60 percent of the traffic; in another set of simulation runs, the SB direction of travel carried 60 percent of the traffic.

Traffic Operational Analysis Results

Table 47 presents the results of the traffic operational analysis of the US 67 roadway section. With the existing configuration of no passing lanes, the US 67 roadway section currently operates at a LOS B or C, depending on the directional split. With the intermediate passing lane configuration, the US 67 roadway section would currently operate at a LOS A. With the maximum passing lane configuration, the US 67 roadway section would currently operate at a LOS A, but with substantially lower percent time spent following values.

The four-lane divided highway configuration would currently operate at LOS A.

Table 47. Summary of Traffic Operational Analysis Results for US 67 Case Study

Lane configuration	Hourly volume (veh/h) NB	Hourly volume (veh/h) SB	Percent time spent following	Average travel speed (mph)	LOS
2003					
Existing configuration (without passing lanes)	257	171	49.8	56.3	B
	171	257	51.0	56.2	C
Intermediate passing lane configuration	257	171	31.3	57.9	A
	171	257	30.7	58.1	A
Maximum passing lane configuration	257	171	22.5	58.7	A
	171	257	21.8	58.9	A

Traffic Safety Analysis Results

Table 48 presents a summary of the traffic safety analysis results for the US 67 case study. The table shows that the anticipated reduction in total nonintersection accident frequency for the intermediate passing lane, maximum passing lane, and four-lane divided highway configurations are 3, 5, and 46 percent, respectively. The table shows that, from a safety standpoint, the four-lane divided highway alternative is substantially more cost effective than the passing lane configurations. However, all of the alternatives for this case study are much less cost effective than the alternatives considered in the other case studies because this site currently experiences fewer accidents per mi than the other sites considered.

Table 48. Summary of Traffic Safety Analysis Results for US 67 Case Study

Lane configuration	Section length (mi)	Length of added lanes (mi)	Percent reduction in nonintersection accident frequency			Cost effectiveness (expenditures per accident reduced over 20-year period)
			F&I	PDO	Total	
Intermediate passing lanes	10.1	4.6[a]	2	3	3	$58,600
Maximum passing lanes	10.1	7.1[a]	5	5	5	$50,200
Four-lane divided highway	10.1	20.2[b]	51	43	46	$24,800

[a] One direction of travel only.
[b] Both directions of travel for entire section length.

Section 12. Conclusions and Recommendations

This section presents the conclusions and recommendations of the research.

Conclusions

The conclusions of the research are presented below:

1. A passing lane is an added lane provided in one or both directions of travel on a conventional two-lane highway to increase passing opportunities. Where a passing lane is provided on a steep upgrade, to provide opportunities to pass slow-moving trucks or recreational vehicles, it is known as a climbing lane.
2. Passing lanes can be used effectively to improve the level of service and the safety performance of two-lane highways.
3. Passing lanes provide lower traffic operational and safety benefits than a four-lane divided highway, but also cost less to construct.
4. An evaluation of three existing passing lane sites on Missouri NHS routes found that those passing lanes improve percent time spent following on those roads by 10 to 31 percent in comparison to a conventional two-lane highway without passing lanes. At one site, the traffic operational level of service was LOS B both with and without the passing lanes, but the level of service was nearly LOS A with passing lanes and nearly LOS C without passing lanes. At a second site, the level of service was LOS B with passing lanes, but would have been LOS D without passing lanes. At a third site, the level of service was LOS A with passing lanes, but would have been LOS C without passing lanes.
5. A safety evaluation found that the accident frequency per mi per year within passing lane sections on two-lane highways is 12 to 24 percent lower than for conventional two-lane highway sections and that the percent difference in accident frequency between roadways with and without passing lanes increases with increasing traffic volume. Provision of a four-lane divided highway, as expected, is more effective than provision of passing lanes in reducing accidents. The accident frequency per mi per year for four-lane divided highways is 29 to 40 percent lower than for conventional two-lane highway sections and the percent difference in accident frequency between four-lane divided and two-lane roadways without passing lanes decreases with increasing traffic volume. Safety prediction models for conventional two-lane highways, two-lane highways with passing lanes, and four-lane highways were developed in the research; these models allow safety predictions to be made for any traffic volume level.

6. Passing lanes were found to be equally effective in reducing accidents in all severity levels. Thus, percentage accident reductions determined from Table 26 apply to both fatal-and-injury and property-damage-only accidents.
7. Case studies of locations on five Missouri NHS routes found that an alternative involving as many passing lanes as practical without overlapping of the passing lanes could be provided for, on the average, 24 percent of the cost provision of a four-lane divided highway. At three of the five case study sites, the maximum passing lane configuration would improve traffic operations for the years 2003 and 2023 by two levels of service (i.e., from LOS D to B or from LOS C to A). At the other two case study sites, the maximum passing lane configuration would improve traffic operations in years 2003 and 2023 by one level of service (i.e., LOS C to B). The case studies found that intermediate passing lane configurations would reduce total accident frequency by 3 to 8 percent; the maximum passing lane configuration would reduce total accident frequency by 6 to 12 percent.

Recommendations

The following recommendations based on the research findings are presented for consideration by MoDOT:

1. In design studies for improvement of traffic operations and safety on existing two-lane highways, the provision of passing lanes should be considered as a design alternative and should be compared to other two- and four-lane highway alternatives. The most desirable alternative should be selected through an evaluation process that, at a minimum, considers level of service, anticipated safety performance, and construction cost.
2. Passing lanes should be considered where needed to reduce delays at specific bottleneck locations, such as upgrades where slow-moving vehicles are present, to improve the traffic operational level of service by breaking up traffic platoons and reducing delays caused by inadequate passing opportunities over substantial lengths of highway, and to improve safety by providing assured passing opportunities without the need for the driver to use the lane normally reserved for opposing traffic.
3. Passing lane configurations should be selected from among the alternatives shown in Figure 3 of this report. For adjoining passing lanes, the "tail-to-tail" configuration shown as (e) in Figure 3 is generally preferable to the "head-to-head" configuration shown as (f) in Figure 3, so that vehicles using the passing lane are not approaching one another in the lane drop areas. Where configuration (f) is contemplated, consideration should be given to alternatives including "tail-to tail" passing lanes, separating the passing lanes with a transition area at least 0.25 mi in length, or overlapping the passing lanes, as shown in configurations (i) and (j).

4. 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.

5. Staged construction of passing lanes should be considered, where appropriate. A limited number of passing lanes can be built at first, with more added as traffic volumes grow. Similarly, staged four-laning, with two-lane highway remaining in gaps between four-lane sections, can provide benefits similar to providing passing lanes at intervals. An advantage of staged construction is that the later project may not be needed if the anticipated traffic volume growth does not occur.

6. Passing lane location should be selected to minimize construction costs. It may, in some cases, be possible to avoid improving portions of the roadway with rough terrain, highway structures, and adjacent development, where passing lane construction would be most expensive.

7. Passing lane locations should appear logical to the driver. The value of passing lanes is more obvious to the driver where passing sight distance is restricted than on long tangent sections which 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 should be avoided, since they may not be suitable for passing.

8. The locations of major intersections and high-volume driveways should be considered in selecting passing lane locations, to minimize the volume of turning movements on road sections where passing is encouraged. Where major intersections or high-volume driveways are present in a passing lane, provision of left-turn lanes should be considered.

9. In locating passing lanes, other physical constraints, such as bridges and culverts, should be avoided if they restrict the provision of a continuous shoulder.

10. Climbing lanes on steep upgrades should be considered where the climbing lane warrants in the AASHTO *Green Book* are met. NCHRP Report 505 provides a spreadsheet program that can be used to determine the speed profile for heavy trucks on specific upgrades.

11. The optimal length for a passing lane in level or rolling terrain ranges between 0.5 and 2.0 mi, depending on the directional flow rate, as shown in Table 6 of this report. Passing lanes shorter than those shown in the table may not be able to satisfy all of the passing demand. Passing lanes longer than those shown in the table may be inefficient because the downstream portion of the passing lane may be underutilized for passing.

12. The lane width in a passing lane section should normally be the same as the lane widths on the adjacent sections of two-lane highway. On Missouri NHS routes, lanes widths of 12 ft should normally be used in passing lane sections.

13. The shoulder width in a passing lane section should not normally be narrower than the shoulder width on the adjacent two-lane highway. Shoulder widths of 10 ft should normally be used in passing lanes on Missouri NHS routes. However, narrower shoulders may be used where this would substantially reduce costs. In no case should the shoulder width be less than 4 ft.

14. The length of the lane drop transition taper at the downstream end of a passing lane should be determined from the MUTCD taper formula as a function of off-peak 85th percentile speed. A wide shoulder is desirable at the lane drop taper to provide a recovery area should drivers encounter a merging conflict.

15. The length of the lane addition transition area at the upstream end of a passing lane should be half to two-thirds of the length of the MUTCD lane drop taper for the appropriate off-peak 85th percentile speed.

16. Advance signing for passing lanes is desirable approximately 0.5 mi upstream of each passing lane. A second advance sign approximately 2 mi upstream of each passing lane is also desirable. A regulatory sign that reads KEEP RIGHT EXCEPT TO PASS should be placed at the beginning of the lane drop taper for each passing lane. Signing in advance of the lane drop of each passing lane should include a lane reduction symbol transition sign (MUTCD W4-2) approximately 1,000 ft upstream of the lane drop taper and a text sign RIGHT LANE ENDS (W9-1) or LANE ENDS MERGE LEFT (W9-2) approximately 500 ft upstream of the lane drop taper.

17. Pavement markings for passing lanes should be marked in accordance with MUTCD Figure 3B-3 (see Figure 21 in this report). MoDOT's normal practice is to mark the opposing direction to a passing lane to permit passing where sight distance exceeds the MUTCD passing sight distance criteria as shown in drawing (a) of Figure 21. There is no general agreement among state highway agencies on the value of lane addition transition markings such as those shown in Figure 22 of this report; no recommendation is being made based on this research, but MoDOT should consider testing of these alternative markings. Lane drop transition markings at the downstream end of a passing lane should be provided in accordance with MUTCD Figure 3B-12 (see Figure 22).

18. The traffic operational benefits of passing lanes should be assessed by determining the effect of the passing lanes on the level of service on the highway. The level of service definitions for two-lane highways, based on percent time spent following and average travel speed, are presented in the *Highway Capacity Manual* (see Table 15 in this report). The TWOPAS model provides the best method for assessing percent time spent following and average travel speed to determine level of service.

19. The safety effectiveness of passing lanes on Missouri NHS routes can be determined from comparisons of the safety performance between specific roadway types developed in this research (see Tables 25 and 26 and associated regression equations presented in this report).

20. The case studies in Section 11 of this report illustrate the types of analyses that should be conducted to evaluate passing lane alternatives considered in design studies for highway improvement projects.

References

1. Transportation Research Board, *Highway Capacity Manual*, 2000.
2. Hoban, C. J., and J. F. Morrall, *Overtaking Lane Practice in Canada and Australia*, Report No. AIR 359-15, Australian Road Research Board, 1985.
3. Harwood, D. W., and C. J. Hoban, *Low-Cost Methods for Improving Traffic Operations on Two-Lane Roads*, Report No. FHWA-IP-87-2, Federal Highway Administration, January 1987.
4. American Association of State Highway and Transportation Officials, *A Policy on Geometric Design of Highways and Streets*, 2001.
5. Harwood, D. W., D. J. Torbic, K. R. Richard, W. D. Glauz, and L. Elefteriadou, *Review of Truck Characteristics as Factors in Roadway Design*, NCHRP Report 505, Transportation Research Board, 2003.
6. Federal Highway Administration, *Manual on Uniform Traffic Control Devices*, Millennium Edition, 2000.
7. Harwood, D. W., and A. D. St. John, *Passing Lanes and Other Operational Improvements on Two-Lane Highways*, Report No. FHWA-RD-85/028, Federal Highway Administration, July 1984.
8. Potts, I. B., and D. W. Harwood, *Application of European 2+1 Roadway Designs,* NCHRP Research Results Digest 275, April 2003.
9. Wooldridge, M. D., C. J. Messer, B. D. Heard, S. Raghupathy, A. H. Parham, M. A. Brewer, and S. Lee, *Super 2 Highways: Two-Lane Rural Highways With Passing Lanes*, Project Summary Report 4064-5, Texas Transportation Institute, 2002.
10. St. John, A. D., and D. W. Harwood, *TWOPAS Users Guide*, Federal Highway Administration, 1986.
11. Taylor, W. C., and M. K. Jain, "Warrants for Passing Lanes," *Transportation Research Record 1303*, Transportation Research Board, 1991.
12. Rinde, E. A., *Accident Rates vs. Shoulder Width: Two-Lane Roads, Two-Lane Roads with Passing Lanes*, Report No. CA-DOT-TR-3147-1-77-01, California Department of Transportation, September 1977.
13. Mutabazi, M. I., E. R. Russell, and R. W. Stokes, "Location and Configuration of Passing Lanes," *Transportation Research Record 1658*, Transportation Research Board, 1999.

14. Mutabazi, M. E., E. R. Russell, and R. W. Stokes, *Review of the Effectiveness, Location, Design, and Safety of Passing Lanes in Kansas,"* Report No. K-TRAN:KSU-97-1, K-TRAN, October 1999.

15. Hostetter, R. S., and E. L. Seguin, "The Effects of Sight Distance and Controlled Impedance on Passing Behavior," *Highway Research Board Bulletin 292*, Highway Research Board, 1965.

16. Fong, H. K., and F. D. Rooney, *Passing Rates Along the First 2000' or 609.6 m of Passing Lanes for Groups of Three or More Vehicles*, Report No. FHWA/CA/TO-96/29, California Department of Transportation, May 1997.

17. Fong, H. K., and F. D. Rooney, *Passing Lane Diverge Tapers*, California Department of Transportation, August 1990.

18. May, A. D., "Traffic Performance and Design of Passing Lanes," *Transportation Research Record 681*, Transportation Research Board, 1991.