Report No. KS-25-03 ▪ FINAL REPORT ▪ December 2025

Kansas Department of Transportation 2025 Passing Lane Guidance

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1 Report No. KS-25-03	**2 Government Accession No.**	**3 Recipient Catalog No.**
4 Title and Subtitle Kansas Department of Transportation 2025 Passing Lane Guidance		**5 Report Date** December 2025 **6 Performing Organization Code**
7 Author(s) Eric J. Fitzsimmons, Ph.D., P.E.; Douglas Harwood, P.E.; Amy Rockers, P.E.		**8 Performing Organization Report No.**
9 Performing Organization Name and Address Kansas State University Transportation Center Department of Civil Engineering 2118 Fiedler Hall 1701C Platt Street Manhattan, KS 66506-5000		**10 Work Unit No. (TRAIS)** **11 Contract or Grant No.** C2181
12 Sponsoring Agency Name and Address Kansas Department of Transportation Bureau of Research 2300 SW Van Buren Topeka, Kansas 66611-1195		**13 Type of Report and Period Covered** Final Report June 2021 – June 2023 **14 Sponsoring Agency Code** RE-0846-01
15 Supplementary Notes For more information write to address in block 9.		

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The report details the use of HCM6 operational procedures, which was preferred over HCM7 for passing-lane analysis, as well as TWOPAS simulation model to evaluate design alternatives and define target levels of service for current and future traffic conditions. Safety effectiveness is addressed through referencing crash modification factors, demonstrating that passing lanes and short four-lane sections can substantially reduce crash frequency.

Geometric design recommendations include lane and shoulder widths, taper design, and preferred passing-lane lengths of 1.5 to 2 miles. Additional improvements that may be incorporated into passing-lane projects are also discussed. Overall, the guidance offers a consistent, research-based framework to support KDOT in enhancing safety and traffic operations on the state's rural two-lane highway system.

17 Key Words Passing lanes, Rural highways, Two lane highways, Geometric design, Traffic safety		**18 Distribution Statement** No restrictions. This document is available to the public through the National Technical Information Service www.ntis.gov.	
19 Security Classification (of this report) Unclassified	**20 Security Classification (of this page)** Unclassified	**21 No. of pages** 63	**22 Price**

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A Report on Research Sponsored by

THE KANSAS DEPARTMENT OF TRANSPORTATION
TOPEKA, KANSAS

and

KANSAS STATE UNIVERSITY TRANSPORTATION CENTER
MANHATTAN, KANSAS

December 2025

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1. INTRODUCTION

This report presents guidelines for use of passing lanes in Kansas. The guidelines were prepared for the Kansas Department of Transportation (KDOT) by Kansas State University (K-State) and Harwood Road Safety LLC.

2. ROLE OF PASSING LANES IN IMPROVING TWO-LANE HIGHWAY OPERATIONS

Passing opportunities on two-lane highways can be limited by heavy truck traffic or frequent no-passing zones. Rural two-lane highways often incorporate passing lanes at intervals to improve passing opportunities. This section of the guidelines presents an overview of the application of passing lanes on rural two-lane highways.

2.1 What Are Passing Lanes?

A passing lane is an additional 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 typically varies from 0.5 miles to 2 miles. As explained in Section 4.2.1, passing lanes longer than 2.0 miles may be inefficient. However, passing lanes longer than 2.0 miles may be used where site-specific conditions indicate a need. Figure 1 illustrates a plan view of a typical passing lane section.

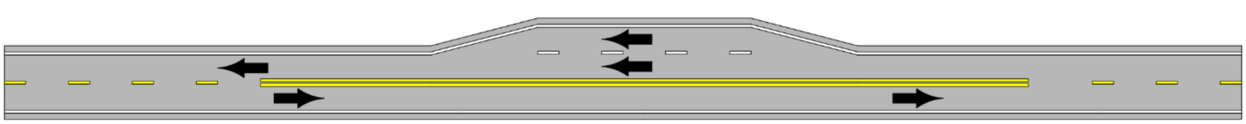

Figure 1: Plan View of Typical Passing Lane Section

Throughout these guidelines, 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.

2.2 What Are Climbing Lanes?

Climbing lanes are passing lanes located on specific upgrades. When upgrades are sufficiently long and steep enough to slow heavy trucks by at least 10 mph or to substantially reduce the traffic operational level of service on the upgrade, climbing lanes can be used.

2.3 Objectives of Using Passing Lanes

The objectives of using passing lanes on a two-lane highway are (Harwood & Hoban, 1987):

- 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; and
- to improve safety by providing 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 and may be achieved by installing climbing lanes for trucks on steep upgrades.

The second objective, to improve overall traffic operations, has evolved more recently. 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 functions, and it is often difficult to draw a clear traffic operational distinction between the two. The distinction is important, however, in planning and design. The evaluation of a climbing lane considers only the bottleneck location, with the objective of improving traffic operations at the bottleneck to at least the same quality of service as adjacent road sections. For passing improvements, on the other hand, the evaluation should consider traffic operations for an extended road length, typically 5 to 50 miles. Furthermore, the location of the passing improvements 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 by providing same direction passing maneuvers and potentially reducing the speed required to overtake a vehicle. A portion of the safety benefit of providing a four-lane divided highway can be obtained through the addition of passing lanes on two-lane highways.

Passing lanes are a unique improvement for two-lane highways because they can improve the level of service (LOS) for the roadway but do not increase the roadway capacity. The capacity of the roadway for each direction of travel is controlled by the roadway segments with only one lane in that direction of travel. The 6th edition of the *Highway Capacity Manual* (HCM) (Transportation Research Board [TRB], 2016) specifies the capacity of a two-lane highway (regardless of whether passing lanes are present) as 3,200 passenger cars/hour for both directions combined (1,700 passenger cars per hour for each direction of travel).

2.4 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 (Harwood & Hoban, 1987; Harwood & St. John, 1985).

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. Figures 2 through 12 provide conceptual representations of different passing lane configurations and are not drawn to scale for design purposes. The following factors should be considered in choosing the appropriate configuration for passing lanes:

Figure 2 illustrates a conventional two-lane highway. Where passing opportunities are not sufficient, a conventional two-lane highway may be improved by the addition of passing lanes.

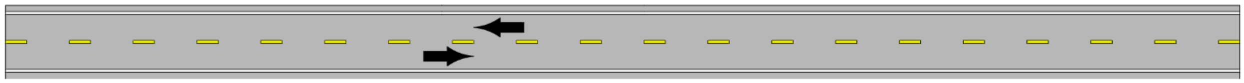

Figure 2: Conventional Two-Lane Highway (Harwood & Hoban, 1987; Harwood & St. John, 1985)

Figure 3 shows a single isolated passing lane. A passing lane of this type would be used to address an isolated traffic platooning issue or as a climbing lane on an upgrade with a reduced level of service.

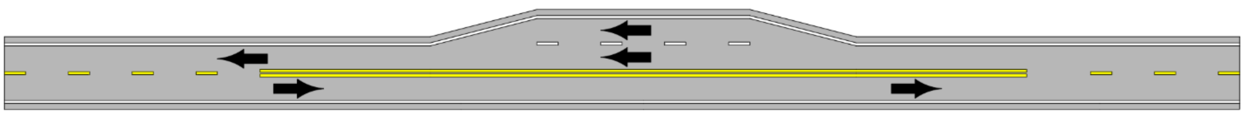

Figure 3: Isolated Passing Lane (Harwood & Hoban, 1987; Harwood & St. John, 1985)

Figures 4 through 7 depict separated or adjoining passing lanes which are often used in pairs with one in each direction of travel at regular intervals along a two-lane highway:

Figures 4 and 5 depict two alternative configurations for separated passing lanes that are generally used to increase passing opportunities on roads where more frequent passing lanes are not needed. The spacing between separated passing lanes should be based on the results of traffic operational analyses as discussed in Section 4.

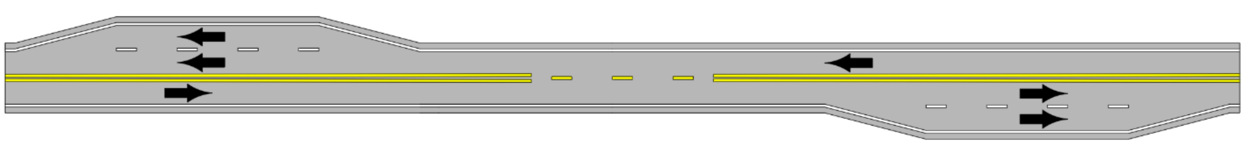

Figure 4: Separated Passing Lanes – Alternative 1 (Harwood & Hoban, 1987; Harwood & St. John, 1985)

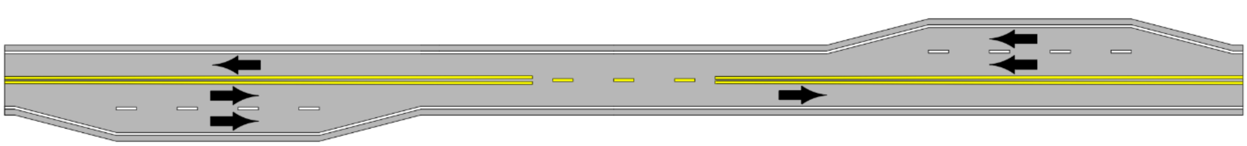

Figure 5: Separated Passing Lanes – Alternative 2 (Harwood & Hoban, 1987; Harwood & St. John, 1985)

Figures 6 and 7 depict adjoining passing lanes which are generally used where traffic volumes and, therefore, passing demands are higher or where constraints such as towns, intersections, structures, or environmentally sensitive areas limit the portions of the roadway where it is desirable to place passing lanes. The configuration in Figure 6 is generally preferred to that shown in Figure 7 because the lane reduction transition areas of the passing lanes in opposite directions of travel are not adjacent. If the transition areas for the configuration shown in Figure 7 terminated end-to-end, there might be a potential opportunity for a vehicle at the lane reduction transition in one direction of travel to continue straight ahead into the lane reduction transition for the opposite direction of travel. Thus, at locations where the configuration shown in Figure 7 makes traffic operational sense, the passing lanes should either be separated by a buffer, typically at least 500 ft in length, or partially overlapped so that the lane-reduction transition areas do not directly adjoin one another. Intersections, bridges, two-way left-turn lanes, or painted medians can often be used effectively to provide a buffer area between opposing passing lanes.

Figures 6 and 7 show the widening for passing lanes being made on the outside of the existing roadway in each direction of travel, which is the typical practice. In constrained situations, it is feasible to shift the centerline of the roadway and partially widen on each side of the passing lane. This alternative typically increases project costs because it involves re-grading the roadway to shift the crown.

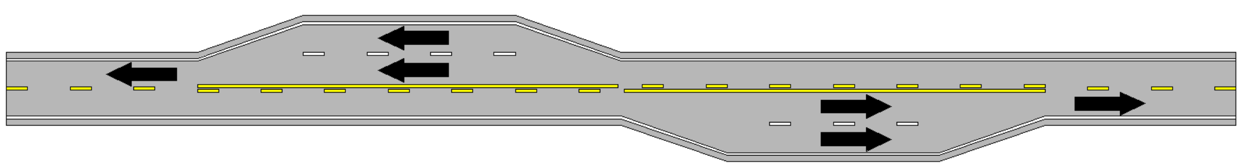

Figure 6: Adjoining Passing Lanes – Alternative 1 (Harwood & Hoban, 1987; Harwood & St. John, 1985)

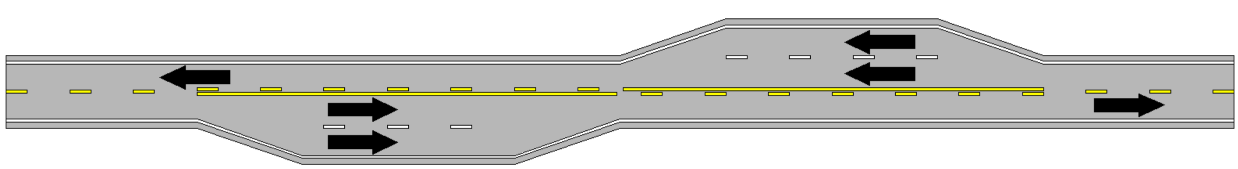

Figure 7: Adjoining Passing Lanes – Alternative 2 (Harwood & Hoban, 1987; Harwood & St. John, 1985)

Figures 8 and 9 depict continuously alternating passing lanes which are a continuous series of passing lanes in alternating directions of travel that may have short buffers, but no gaps, between the passing lanes. These are sometimes appropriate over an extended section of roadway, particularly where traffic volumes are very high or where a wide pavement section is available to reconfigure for a passing lane. When adding a continuously alternating passing lane, where the existing two-lane pavement is not being reconstructed, the configuration in Figure 8 may be preferred to that in Figure 9, since pavement is added to only one side of the road and the lanes do not need to be reconfigured as in Figure 9. Figure 9 may be more favorable where an existing wider pavement section exists and could be converted to passing lanes without widening or converted by minimal widening on each side. While Figure 9 depicts an acceptable layout, KDOT has not developed guidance on buffer lengths or developed related standard drawings for this layout. These would need to be developed before the layout shown in Figure 9 could be utilized. The KDOT Bureau of Traffic Engineering would also need to be contacted to discuss pavement marking maintenance.

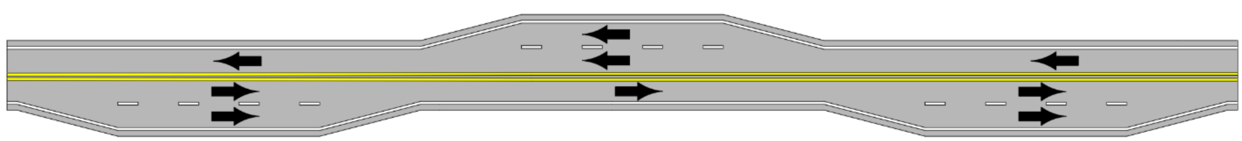

Figure 8: Continuously Alternating Passing Lanes – Alternative 1 (Harwood & Hoban, 1987; Harwood & St. John, 1985)

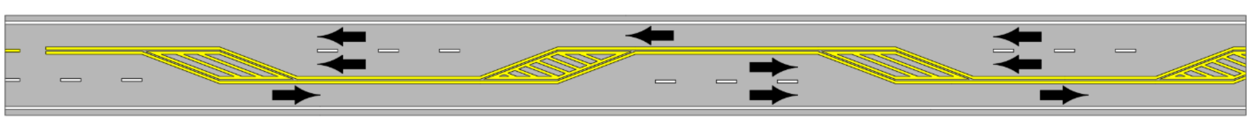

Figure 9: Continuously Alternating Passing Lanes – Alternative 2 (Harwood & Hoban, 1987; Harwood & St. John, 1985)

Figures 10 and 11 depict overlapping passing lanes which are often used at crests where a climbing lane is provided on each upgrade or where there is insufficient space to utilize the passing lane configuration shown in Figure 7 with a buffer between the passing lanes.

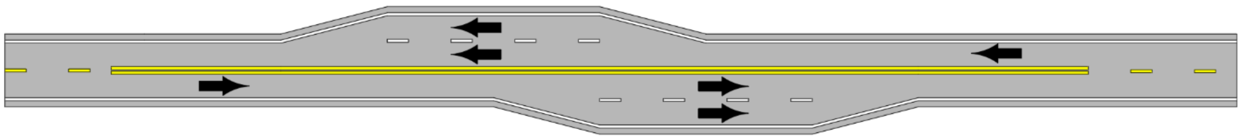

Figure 10: Overlapping Passing Lanes – Alternative 1 (Harwood & Hoban, 1987; Harwood & St. John, 1985)

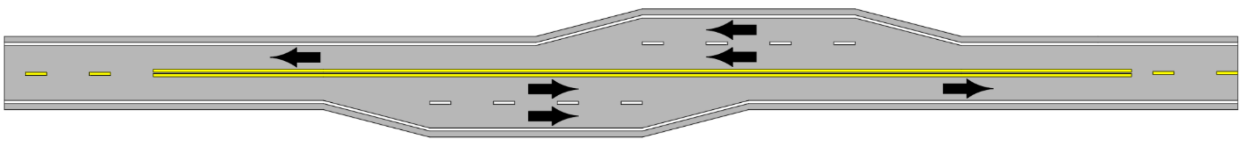

Figure 11: Overlapping Passing Lanes – Alternative 2 (Harwood & Hoban, 1987; Harwood & St. John, 1985)

Figure 12 depicts side-by-side passing lanes which are in effect, short four-lane sections. Short four-lane sections are generally undivided roadways, but may be constructed as divided roadways, if the ultimate design planned for the highway is a continuous four-lane divided roadway. Construction of a short four-lane section can provide a substantial proportion of the benefits of the ultimate design for a relatively small proportion of the total cost of an extended four lane configuration, particularly if major bridge work or right-of-way acquisition can be avoided. However, where the ultimate design is uncertain, or the need for it is many years away, the use of other passing lane alternatives is less costly than a short four-lane divided alternative.

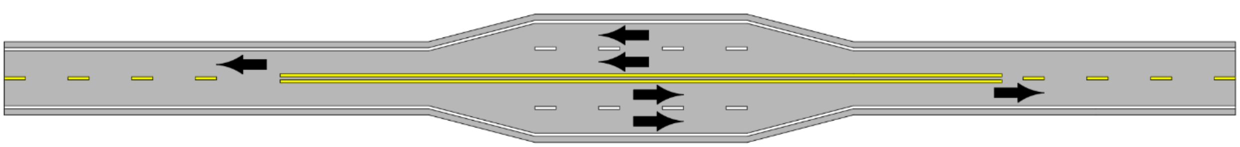

Figure 12: Side-by-Side Passing Lanes (Harwood & Hoban, 1987; Harwood & St. John, 1985)

The selection among these passing lane configurations is strongly influenced by present and future traffic volumes and the present and future traffic operational level of service on the roadway. These traffic operational considerations are addressed in Sections 4 and 7 of these guidelines. The selection is also influenced by the geometric features, existing roadway network, impacts on the surrounding areas and construction costs as expressed in Section 3.

3. LOCATION GUIDELINES FOR PASSING LANES

Where 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 issue 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.

Where 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. The remainder of this section presents guidelines for locating passing lanes, including climbing lanes on upgrades.

3.1 Location Guidelines for Passing Lanes

To the greatest extent practical, passing lanes should be located where their traffic operational benefits will be highest and their impact on the surroundings and construction costs will be lowest. There will often be tradeoffs between traffic operational benefits, effects on the surroundings, and construction costs that need to be considered. A more detailed discussion of the location guidelines for passing lanes follows:

- Passing lanes should generally be placed where traffic platooning is highest. It may be desirable to place passing lanes just downstream of a town, a major intersection, or a series of horizontal curves so that any platoons formed in those areas can be dissipated. Sections 4 and 7 provide guidance on traffic operational analyses that can assist in locating passing lanes effectively.
- Passing lanes should be placed, when practical, at locations where there is a substantial length of uninterrupted roadway downstream where traffic operational benefits can be obtained. For example, it generally would not make sense to locate a passing lane just upstream of a town because the

potential downstream benefits of the passing lane might be quickly dissipated as traffic passes through the town. Section 4 provides additional guidance on the downstream traffic operational benefits of passing lanes.

- A key 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. 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, existing structures that would be expensive to widen, major utilities requiring relocation, and major intersections, high-volume driveways, and driveways that serve large and/or heavy vehicles on a daily basis. Refer to the KDOT (2013) *Access Management Policy* for more detailed information on access types.
- It is also desirable when locating passing lanes to avoid sensitive environmental areas, such as wetlands, and areas of historical or archeological interest.
- 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, placement of passing lanes on highway sections with low-speed curves that slow all traffic should be avoided, since such locations may not be suitable for passing; where all traffic must slow for a curve, drivers that wish to pass an impeding vehicle will not have any speed advantage over the vehicle they wish to pass.

- The passing lane location may be on a sustained upgrade or on a roadway section in level or rolling terrain. If delay problems on the grade are severe, the upgrade 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 on upgrades than at other locations. Many vehicles are not slowed by upgrades as dramatically as heavy trucks, so passing lanes in level or rolling terrain may provide opportunities to pass such vehicles that are just as good as on upgrades. Passing lanes are also effective in level or rolling terrain where the demand for passing opportunities exceeds supply.
- When considering a passing lane location, having more than minimum sight distance at the lane-addition and lane-reduction tapers is desirable. 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. Where the presence of higher-volume intersections or driveways cannot be avoided, special provisions for turning vehicles, such as provision of auxiliary turn lanes, should be considered. Low-volume intersections and driveways do not usually create problems within passing lanes; however, it is desirable to avoid locating the lane-addition and lane-reduction transitions near intersections or driveways, since turning movements are not desirable where drivers may be focused on changing lanes.
- Other physical constraints, such as bridges and culverts, should be avoided, where practical, if their presence within a passing lane increases the construction cost or restricts the provision of a continuous shoulder.

Passing lanes also lend themselves well to being constructed in phases over time. Initially, a few passing lanes spaced at, for example, 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 constructing the passing lanes in phases is that this plan is less dependent on the accuracy of traffic volume forecasts. If a large increase in traffic volumes that have been forecast never materializes, then the next stage of passing lane development need not be built. With building a four-lane highway, the entire investment is made up front, and the benefit of that investment may not be reaped if the traffic volume does not increase as forecasted.

3.2 Location Guidelines for Climbing Lanes

The American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Street* (AASHTO, 2018), hereon referred to as the *Green Book,* 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 exists:
    - 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

These criteria indicate that a climbing lane may be provided when the criteria are met, not that a climbing lane must be provided. These criteria are incorporated in Section 7.15 of the KDOT (2014) Bureau of Road Design manual.

Figure 3-21 (Critical Lengths of Grades for Design, Assumed Typical Heavy Trucks of 200 lb/hp) in the 2018 *Green Book* (AASHTO, 2018) shows the critical length of grade that will result in various speed reductions for a truck making it a useful tool in assessing the need for climbing lanes.

Where the climbing lane criteria are not met, an upgrade may be an appropriate location for a passing lane to provide passing opportunities and improve the overall level of traffic service on a roadway, as the presence of the upgrade may slow some vehicles and, thus, make it easier for other vehicles to make passing maneuvers.

Typically, a climbing lane should extend from the point on the upgrade at which the speed of a specific design truck has been slowed by 15 mph below the operating speed and should end at a point where the design truck has recovered speed to within 10 mph of the operating speed and located at least 300 ft beyond the crest of the upgrade. Climbing lane terminals should be located away from intersections and bridges. Both the passing sight distance and stopping sight distance should be available at each end of the climbing lane.

4. TRAFFIC OPERATIONAL EFFECTIVENESS OF PASSING LANES

This section addresses the traffic operational effectiveness of passing lanes by explaining 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, 6th Edition* (HCM6) (TRB, 2016). Specific estimates of the traffic operational effects of passing lanes are presented herein.

4.1 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 presented in Table 1. For roadways with posted speed limits of 60 mph, a no-passing zone is considered warranted where the passing sight distance falls below 1,100 ft. Thus, passing is prohibited where sight distance is limited and passing drivers might be unable to see an opposing vehicle in time to take appropriate action. The *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) (FHWA, 2009) recommends 400 ft as the minimum length of passing zones; passing zones as short as 400 ft provide an opportunity to pass slow-moving vehicles but are not usually suitable for high-speed passing maneuvers. Some roads with many short passing zones 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. Passing opportunities decrease as traffic volumes increase because there are fewer adequate gaps in the 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 travel time that drivers spend following other vehicles, referred to as percent time spent following, is one of the measures of effectiveness used by the 6th edition of the *Highway Capacity Manual* (HCM6) (TRB, 2016) to define the level of service on two-lane highways.

Table 1: Minimum Passing Sight Distance for Placement of No-Passing Passing Zone Markings

85th percentile or posted or statutory speed limit (mph)	Minimum passing sight distance (ft)
25	450
30	500
35	550
40	600
45	700
50	800
55	1,000
60	1,100
65	1,100

NOTE: This table is based on KDOT typical practices and Engineering Judgement.

4.2 HCM 6th Edition Level of Service Procedures

The HCM6 (TRB, 2016) 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 rural two-lane arterial 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 defined as 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 directly in the field. However, the HCM6 states that the percentage of vehicles traveling at headways of less than 3 seconds at a representative location can be used as a surrogate measure to estimate percent time spent following.

Average travel speed represents the mobility on a rural 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 HCM6 defines the level of service for three classes of rural 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, that serve as scenic or recreational routes that are not primary arterials, or that pass through rugged terrain are generally assigned to Class II. Class II facilities most often serve relatively

short trips, the beginning or ending portion of longer trips, or trips for which sightseeing plays a significant role.

- Class III—These are two-lane highways that serve moderately developed areas. They may be portions of a Class I or Class II highway that pass through small towns or developed recreational areas. Local traffic often mixes with through traffic on these segments, and the number of unsignalized driveways and cross-streets is noticeably higher than in a purely rural area. Class III highways can include longer roadway segments passing through more spread-out recreational areas, also with increased roadside densities. Such segments are often accompanied by reduced speed limits that reflect the higher activity level.

Passing lanes are generally appropriate on Class I highways, where the lack of ability to pass is the major determinant of the traffic operational LOS. Any two-lane highway for which passing lanes are a logical improvement type is, almost by definition, a Class I highway. Because efficient mobility is of paramount importance on Class I highways, both percent time spent following and the average travel time are used to define the level of service. Passing lanes are not as likely to be needed on two-lane highways in Classes II and III.

The level-of-service criteria for Class I highways are presented in Table 2. On high-speed roadways, the level of service is defined primarily by percent time spent following. However, roadway alignments with reduced design speeds may have reduced average travel speeds and, therefore, may limit the level of service that can be achieved.

Table 2: Level of Service Criteria for Two-Lane Highways in Class I (TRB, 2016)

LOS	Percent time spent following	Average travel speed (mph)
A	≤ 35	> 55
B	> 35-50	> 50-55
C	> 50-65	> 45 - 50
D	> 65-80	> 40 - 45
E	> 80	≤ 40

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

Most rural two-lane arterials on level or rolling terrain, like most Class I arterials in Kansas, have average travel speeds well above 55 mph, so the LOS of such highways is not limited by average travel speed. Therefore, the LOS for higher speed rural two-lane arterials is generally a function of percent time spent following only.

HCM6 Chapter 15 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 LOS 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

4.2.1 Traffic Operations in Passing Lanes

The effect of a passing lane on traffic operations on a two-lane road is illustrated by Figure 13. 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. HCM6 Chapter 15 includes traffic operational analysis procedures to estimate average travel speed and percent time spent following and, using those measures, to determine the traffic operational LOS for the roadway.

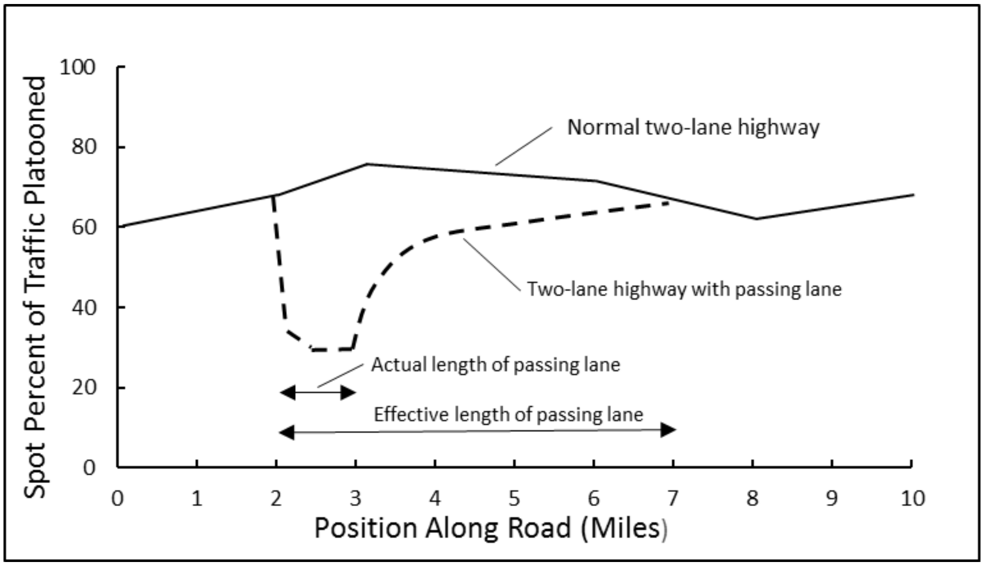

Figure 13: Example of the Effect of a Passing Lane on Two-Lane Highway Traffic Operations (Harwood & Hoban, 1987)

The HCM6 shows that percent time spent following will be reduced within a passing lane to slightly less than half of its upstream value and that, depending upon traffic volume, the reduction in percent time spent following will persist for 4 to 13 mi downstream of the passing lane. Thus, passing lanes can improve level of service not only within the length of the passing lane itself but also for a substantial distance downstream of the passing lane. Passing lanes increase average travel speed by 8 to 11 percent, depending upon traffic volume, within the passing lane itself. The speed benefits of passing lanes persist for approximately 2 mi downstream of the passing lane. These are typical average effects of passing lanes that may vary substantially from site to site, depending on traffic and roadway characteristics.

Table 3 summarizes the percentage change in the percent time spent following and average travel speed within a passing lane as a function of traffic volume. This table is based on the HCM6 procedure. A KDOT study led by the Bureau of Transportation Planning, *Development of Passing Lane Performance & Planning-Level Passing Lane Effectiveness Evaluation (DRAFT),* found that the directional flow rate on most Class I routes in Kansas is 350 pc/h or less. Review of the data collected on these routes indicates travel speed increases and reduction in percent time spent following were modest. The average speed increase was 1–3 mph. The average reduction in percent time spent following was 5–15%. Further data collection and research are being conducted by KDOT to better quantify values experienced in Kansas.

Table 3: Increase in Average Travel Speed and Decrease in Percent Time Spent Following Within a Passing Lane (adapted from TRB, 2016)

Directional flow rate (pc/h)	Average travel speed (mph)	Percent time spent following
0-300	+8	–58
> 300-600	+10	–61
> 600	+11	–62

NOTE: The units, pc/h, based on the *Highway Capacity Manual* (TRB, 2016), represent passenger car equivalents per hour. The passenger car equivalent volume is the traffic volume in veh/h, with greater weight given to trucks than passenger cars.

Table 4 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. This table is based on the HCM6 procedures. The KDOT study *Development of Passing Lane Performance & Planning-Level Passing Lane Effectiveness Evaluation (DRAFT)* only collected values for percent time spent following at a few locations and found the length of roadway affected to be 8 to 10 miles. Further data collection and research are being conducted by KDOT to better quantify values experienced in Kansas.

Table 4: Downstream Length of Roadway Affected by Passing Lanes on Directional Segments in Level and Rolling Terrain (adapted from TRB, 2016)

	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
700	5.7	1.7
≥ 1000	3.6	1.7

NOTE: The units, pc/h, based on the HCM6 (TRB, 2016), represent passenger car equivalents per hour. The passenger car equivalent volume is the traffic volume in veh/h, with greater weight given to trucks than passenger cars.

Table 5 presents a range of typical passing lane lengths in level and rolling terrain presented in the HCM6. Since the data provided by the KDOT study *Development of Passing Lane Performance & Planning-Level Passing Lane Effectiveness Evaluation (DRAFT)* vary from the values found in Tables 3 and 4, Table 5 is provided only as a reference. With KDOT's in-service experience with passing lanes, KDOT prefers passing lanes to be 1.5 to 2.0 miles where physical conditions allow. Experience has shown this to provide a more comfortable passing maneuver for drivers regardless of traffic conditions.

A Texas DOT research project, *Design Guidelines for Passing Lanes on Two-Lane Roadways (Super 2)* (Wooldridge et al., 2001) conducted simulations on passing lanes of various lengths and spacing for two-way volumes between 400 and 1000 veh/h. The research results indicated that passing lane lengths of 1.5 to 2.0 mi provided the best operations, because the downstream portion of passing lanes longer than 2.0 mi in length generally served very few passing maneuvers. Additional passing-lane length provides diminishing additional benefit compared to adding another passing lane elsewhere. Thus, it would be desirable to end the passing lane at 2.0 miles in length and introduce another passing lane downstream where passing demand has built up.

Traffic simulation modeling (see Section 4.4) may be used to evaluate site-specific values and to help achieve a target LOS. KDOT suggests that passing lanes as short as 0.50 mi only be considered on roadways with lower speeds, lower volumes, or in constrained locations.

Table 5: Passing Lane Lengths (Harwood & St. John, 1985)

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

NOTE: The units, pc/h, based on the HCM6 (TRB, 2016), represent passenger car equivalents per hour. The passenger car equivalent volume is the traffic volume in veh/h, with greater weight given to trucks than passenger cars.

4.2.2 Evaluation of Specific Passing Lane Configurations

The design process for passing lanes on two-lane highways is driven primarily by the goal of achieving a specific target LOS. Passing lanes also provide safety benefits, which should also be considered in the design process. Specific alternative passing lane arrangements (including configurations, locations, and lengths) are generally identified as candidates, assessed with available tools, and compared, leading to the selection of a preferred alternative. The traffic operational tools available for such analyses are discussed below. Section 4.4 addresses the application of these traffic operational analysis tools.

The HCM6 Chapter 15 (TRB, 2016) analysis procedures for rural two-lane highways include procedures for assessing the effect of passing and climbing lanes on level of service. These procedures address only the simplest of added lanes—an isolated passing or climbing 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). Furthermore, the HCM6 uses only a generalized representation of the highway alignment (based on classification as level, rolling, or mountainous terrain) and does not explicitly consider the actual level of traffic platooning or the actual speed distributions of passenger cars, trucks, and recreational vehicles (RVs) on the roadway being assessed. Thus, the HCM6 procedures cannot assess the traffic operational effects of combinations or systems of passing lanes along a two-lane highway where a new passing lane begins before the effective length of a previous passing lane ends. Furthermore, the HCM6 analysis results, even for isolated passing lanes, are based on typical or average assumptions. Greater accuracy in the assessment of the traffic operational effects of passing lanes can best be obtained with a computer simulation model.

Please note that while TWOPAS is mentioned in the following paragraphs, this guide is not declaring it is the only computer simulation software that could be used for analysis. TWOPAS (IHSDM, 2018) is a microscopic computer simulation model of traffic on two-lane highways developed for the Federal Highway Administration (FHWA) 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 or climbing 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 the same sequence of vehicles and drivers can be run through 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 HCM6 to define level of service. In fact, the current HCM6 procedures for two-lane highways were developed with TWOPAS, so it provides results that are consistent with the HCM6.

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 low, 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.

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.

TWOPAS serves as the traffic analysis module for rural two-lane highways in the FHWA Interactive Highway Safety Design Model (IHSDM) software, which is available on the Internet as a free download (IHSDM, 2018). FHWA has ceased updating IHSDM, but the software is still available for use. The application of TWOPAS is addressed further in Section 4.4.3.

TWOPAS should provide results that are more sensitive to site-specific conditions than the HCM6. Thus, both the HCM6 and TWOPAS, or other similar software, are appropriate traffic operational analysis tools.

4.3 HCM 7th Edition Procedures

The 7th edition of the Highway Capacity Manual (HCM7) (TRB, 2022) presents a new traffic operational analysis procedure for two-lane highways intended to replace the HCM6 procedures. The HCM6 service measures for rural two-lane highways, average travel speed and percent time spent following, have been replaced in the HCM7 by a new service measure, follower density. Follower density is defined as the number of vehicles in follower state per mile per lane. Follower density can be computed as the percent followers in the traffic stream times the traffic density. Percent followers is defined in the HCM7 as the percentage of vehicles following another vehicle within 2.5 sec, as opposed to 3.0 sec that was used in the HCM6.

Analyses with the HCM7 procedures, using the Highway Capacity Software (HCS) Version 7.9, have found that the service measure, follower density, does not appear to be sensitive to the presence or absence of passing lanes. Because of software limitations, it has not been possible to verify that the HCM7 procedures are useful for passing lane analysis, and it is recommended that the HCM6 procedures be used instead.

4.4 Traffic Operational Analysis Procedures for Layout and Design of Passing Lanes

This section presents the traffic operational analysis procedures applicable to design analyses for two-lane highways that are candidates for inclusion of passing lanes. Because the HCM7 traffic operational analysis procedures do not appear to be sensitive to the presence of passing lanes, the procedures presented here are based on the HCM6. The steps in the recommended traffic operational analysis procedures are as follows:

- Define target LOS for design year
- Apply HCM6 traffic operational analysis procedures for specific design alternatives

- Apply TWOPAS traffic simulation model to specific design alternatives (optional)
- Assess LOS for existing conditions and the design year
- Select preferred alternative and consider staged construction priorities

Each of these steps is discussed below.

4.4.1 Define Target LOS for the Design Year

The traffic operational objective for the design year is to provide at least a selected target LOS for the completed highway in the design year. The design year is typically 20 years after the likely completion date of the project (or completion of its first stage if staged construction is considered). Design years more than 20 years in the future may be used, where appropriate, but the forecasts of future traffic volume will likely decrease in accuracy as the analysis period is extended.

The target LOS is a project-specific choice. The target LOS should be selected considering the full context of the project and the position of the project within the highway network. Factors including functional classification, terrain, and distances traveled by motorists on the route on which the project is located may influence the choice of target LOS.

On many rural two-lane highway corridors, installation of passing lanes will be needed to provide the target LOS in the design year. The length of passing lanes needed in particular corridors may be longer or shorter depending on the forecast traffic volumes and other traffic and roadway characteristics. To achieve a target LOS as traffic grows over time, passing lanes may also be added in a phased implementation. For example, providing passing lanes every 20 miles until traffic grows and passing lanes are needed every 10 miles to achieve the target LOS. Even if no passing lanes are needed to provide the target LOS, passing lanes may be desirable to reduce crashes or to mitigate delays due to slow-moving trucks on grades.

4.4.2 Apply HCM6 Traffic Operational Analysis Procedures

The LOS within the project limits should be assessed for the following scenarios, as a minimum:

- Existing roadway with peak hour traffic volumes for the current year and/or the KDOT letting year
- Existing roadway with peak hour traffic volumes forecast for the design year (typically 20 years from the letting date)
- Candidate design alternatives with peak hour traffic volumes for the current year and/or the KDOT letting year
- Candidate design alternatives with peak hour traffic volumes forecast for the design year (typically 20 years from the letting date)
- 1.5–2 mile passing lane length that can be adjusted to fit within physical limitations of the corridor.

It is usually not necessary to complete an LOS assessment for every conceivable design alternative for the project. An iterative process may be used, adding passing lanes to the existing roadway until the target LOS is achieved. Once a configuration that achieves the target LOS is identified, variations of that design alternative can be considered to find the best locations for individual passing lanes that provide the target LOS and minimize construction costs and environmental impacts.

For analysis purposes, an extended highway section should be divided into shorter roadway segments that are relatively homogeneous with respect to traffic volume, traffic speed, and roadway characteristics. Traffic operational analysis segments typically begin and end at major intersections, where traffic volumes change, but could also be located at a change in terrain or a substantial change in cross section dimensions. Traffic operational analysis segments should typically be 5 to 20 mi in length.

The traffic operational analysis procedure in HCM6 Chapter 15 (TRB, 2016) is a fundamental tool for LOS assessment in the design of two-lane highways. The HCM6 Chapter 15 procedure accounts for the effects on LOS of demand flow rates, percent trucks, percent RVs, general terrain classes (level, rolling, and mountainous), estimated free-flow speed, and percent no-passing zones.

Demand flow rates, percent trucks, and percent RVs are generally obtained from planning data, which may be supplemented by field traffic counts. The demand flow, a rate used in the HCM6 procedures, represents the traffic flows in each direction of travel in the peak 15-min period of the peak hour or design hour. The design hour generally represents the 30th highest hourly traffic flow of the year. Demand flow rates can be estimated from annual average daily traffic (AADT) volume data using factors that account for the typical proportion of total daily traffic within the design hour (K), the typical directional split of traffic within the design hour (D), and the peak hour factor (PHF) which represents the ratio of the peak 15-min period to the peak hour flow. The values of K, D, and PHF vary between sites and should be estimated based on local knowledge or field data.

The three terrain classes (level, rolling, and mountainous) are defined in the HCM6. Most locations in Kansas are likely to be classified as level or rolling terrain.

Free-flow speeds are generally determined separately for each direction of travel on the roadway. Free-flow speeds can be measured in the field as the mean speed of unimpeded vehicles during a time period with two-way traffic flows of less than 200 veh/h. Alternatively, the HCM6 provides a procedure to estimate a base free-flow speed (BFFS) and adjust the BFFS with factors that represent the lane width, shoulder width, and percentage of no-passing zones on the roadway.

The percentage of the roadway length with no-passing zones for each direction of travel can be determined by measurements in the field or on aerial photographs.

The traffic operational effects of passing lanes can be assessed with the HCM6 Chapter 15 procedures based on the length of the passing lane (including the lane-addition and lane-reduction tapers) and its location relative to the beginning and end of the analysis segment.

The HCM6 defines the LOS for rural two-lane highways in Class I (typically rural arterials), including highways with passing lanes, based on two service measures – average travel speed and percent time spent following. These measures are defined in Section 4.2. The HCM6 Chapter 15 procedures can be applied to estimate the values of average travel speed and percent time spent following by direction of travel for any rural two-lane highway and, thus, assess the applicable LOS.

Table 6 shows the HSM definitions for each LOS level. For operational analysis of two-lane highways, it is often convenient to subdivide LOS B, C, and D to define LOS B+, B, B-, C+, C, C-, D+, D, and D-, as shown in Table 6. Each of these redefined LOS levels represents a 5-percent range in percent time spent following. Redefining LOS in this way for internal project analysis purposes makes it easier to compare the relative performance of specific passing lane alternatives.

The HCM6 Chapter 15 procedures can be applied most easily with the Highway Capacity Software (HCS), Version 6, available from the University of Florida McTrans Center. Other software tools may also be available to apply the HCM6 Chapter 15 procedures.

4.4.3 Apply TWOPAS Traffic Simulation Model

A more detailed traffic operational assessment of passing lane design alternatives can be applied with a traffic simulation model known as TWOPAS. TWOPAS can provide more realistic results than the HCM6 traffic operational analysis procedures because TWOPAS:

- considers the actual horizontal and vertical alignment of the roadway rather than just a general terrain class
- considers the actual locations and lengths of passing and no-passing zones marked on the roadway rather than just the overall percentage of no-passing zones
- considers the actual level of traffic platooning in the traffic stream entering the roadway at the ends of the analysis segment
- considers the actual speed distributions for passenger cars, trucks, and RVs on the roadway and
- accurately determines the traffic operational effects of continuously alternating passing lanes or passing lanes that are closer together than the downstream lengths shown for percent time spent following in Table 4.

Table 6: Redefined Level of Service Criteria for Two-Lane Highways in Class I for Internal Use in Project Analyses

LOS	Percent time spent following	Average travel speed (mph)
A	< 35	> 55
B+	> 35-40	> 50-55
B	> 40-45	> 50-55
B-	> 45-50	> 50-55
C+	> 50-55	> 45 - 50
C	> 55-60	> 45 - 50
C-	> 60-65	> 45 - 50
D+	> 65-70	> 40 - 45
D	> 70-75	> 40 - 45
D-	> 75-80	> 40 - 45
E	> 80	< 40

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

Depending on traffic and roadway characteristics, TWOPAS may provide estimates of average travel speed and percent time spent following that are larger than, smaller than, or about the same as the results provided by the HCM6 traffic operational analysis procedure. The use of TWOPAS for analysis of design alternatives for projects including passing lanes is optional but should be considered where passing lanes are closer together than the downstream lengths shown for percent time spent following in Table 4 or where traffic or roadway conditions may be atypical. TWOPAS can simulate the operation of two-lane roadways with and without passing lanes and of passing lanes with various locations, lengths, and configurations.

The input data needed to apply TWOPAS to a two-lane highway analysis segment includes:

- Demand traffic volume in each direction of travel
- Percent trucks
- Percent RVs
- Desired speed (mph) for passenger cars, trucks, and RVs
- Standard deviation of desired speed (mph) for passenger cars, trucks, and RVs
- Entering percent of traffic platooning

- Horizontal alignment
- Vertical alignment
- Posted speed limit
- Cross section dimensions (including shoulder type)
- Passing sight distance (ft) by location
- No-passing zone locations

Each TWOPAS run incorporates a user-specified random number seed (i.e., an arbitrary integer value used to generate a sequence of random numbers). The random numbers are used to formulate the traffic streams entering at each end of the simulated roadway and to guide the decisions of simulated drivers as they encounter various traffic situations on the roadway. Multiple simulation runs with different random number seeds can replicate normal (day-to-day) variations in traffic conditions. For this reason, TWOPAS analyses are usually based on the combined results of approximately five simulations runs with different random number seeds, so that normal day-to-day variations are considered.

A key strength of TWOPAS is that, if simulation runs are made for two or more different design alternatives with the same input data, including the same random number seeds, the model will simulate identical traffic streams moving through the various design alternatives. Any differences in the results obtained will result from the differences in the design alternatives.

TWOPAS was used in developing the HCM6 Chapter 15 analysis procedures by applying TWOPAS to average conditions, so TWOPAS analyses are compatible with HCM6 analyses. For individual sites, TWOPAS should provide results that are more sensitive to site-specific conditions.

4.4.4 Compare Results and Consider in the Selection of a Preferred Alternative

The final step in the traffic operational analysis is to compare the results obtained for various design alternatives and consider those results in the selection of a preferred alternative for improvement of the existing roadway to a highway with passing lanes. All guidance presented in Sections 2 through 7 should also be considered in selecting the preferred alternative. Constructing passing lanes in phases as an alternative should be considered if only some of the planned passing lanes are needed to provide the target LOS in the early portion of the design analysis period. Potential improvements to the two-lane highway sections between passing lanes are discussed in Section 6.6.

5. CRASH REDUCTION EFFECTIVENESS OF PASSING LANES

Safety evaluations have shown that passing lanes and short four-lane sections reduce crashes below the levels found on conventional two-lane highways. The safety effectiveness of passing lanes on rural two-lane highways is reviewed below.

5.1 Overall Safety Effectiveness of Passing Lanes

Safety effectiveness estimates can be presented in two alternative forms:

- Percentage reduction in crash frequency resulting from implementation of an improvement
- Crash modification factor (CMF), expressed as the value of one minus the percentage reduction in crash frequency expressed as a proportion

The AASHTO *Highway Safety Manual* (HSM) (AASHTO, 2010) Chapter 10 estimates the overall safety effectiveness of passing lanes on rural two-lane highways as follows:

- Passing lane in one direction of travel – 25 percent reduction in crash frequency for all crash severity levels (equivalent to a CMF value of 0.75)
- Short four-lane section (side-by-side passing lanes) – 35 percent reduction in crash frequency for all crash severity levels (equivalent to a CMF value of 0.65)

These reductions in crash frequency apply, within limits of the passing lane from beginning of lane addition taper to end of lane reduction taper, to all crash severity levels and apply to isolated, alternating, and continuous alternating passing lanes, including climbing lanes.

The safety effectiveness estimates for passing lanes presented above might be taken at face value to mean that use of short four-lane sections will reduce more crashes than conventional passing lanes. In fact, the opposite is true because using short four-lane sections improve only half the roadway length than conventional passing lanes in one direction will. As an example, compare two alternatives for a 5-mi two-lane highway section that experiences 20 crashes per mi over a 20-year period. Installation of two 1-mi passing lanes would be expected to reduce:

20 x 2 x 0.25 = 10 crashes

over the 20-year period. Installation of a 1-mi short four-lane section would be expected to reduce:

20 x 1 x 0.35 = 7 crashes

over the same 20-year period.

5.2 Lane Addition and Lane Reduction Transitions

The HSM safety effectiveness estimates presented above include effects on crashes in the lane-addition and lane reduction transition areas. Earlier research (Harwood & St. John, 1985) found no indication of any crash patterns in either the lane-addition or lane reduction transition areas of passing lanes. In field studies of traffic conflicts and erratic maneuvers at the lane reduction transition areas of 10 passing lanes, the lane-reduction transition areas were found to operate smoothly. Overall, 1.3 percent of the vehicles passing through the lane-reduction 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-reduction transition areas in passing lanes were much smaller than the rates found in lane-reduction transition areas at other locations on the highway system, such as in work zones.

5.3 Marking of No-Passing Zones for Opposing-Direction Vehicles at Passing Lanes

KDOT policy is to prohibit passing by vehicles traveling in the opposing direction to a passing lane. To implement this policy, a double yellow centerline should be marked throughout the length of each passing lane and 350 ft beyond the end of the taper at each end of the passing lane. This marking pattern is illustrated in Figure 14.

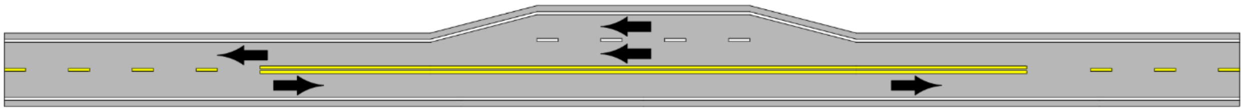

Figure 14: Passing Not Permitted into Opposing Lane of Passing Lane

5.4 Intersections Within Passing Lanes

Research for the Kansas Department of Transportation (KDOT, 2025) 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. However, the research recommended caution in locating intersections within passing lanes. High-volume intersections and intersections in the lane-addition and lane-reduction areas were discouraged; in general, it is recommended that intersections be located near the middle of a passing lane, rather than near the ends. Layouts for pavement marking and signing for lane-reduction transitions near intersections are presented in the Appendix.

6. GEOMETRIC DESIGN OF PASSING LANES

Geometric design of passing lanes should consider lane and shoulder widths, other cross-section elements, lane-addition and lane-reduction taper designs, and intersection treatments. This section addresses these geometric design elements. All design elements not explicitly addressed here should be designed in accordance with the KDOT (2014) Bureau of Road Design manual.

As discussed in Section 2, the objectives of adding passing lanes to an existing two-lane highway are to reduce delay, improve overall traffic operations, and improve safety. The objectives are consistent with the objectives of resurfacing, restoration, and rehabilitation (3R) projects. Thus, improvement of an existing two-lane highway to add passing lanes may be defined as a 3R improvement.

6.1 Cross Section

Where a section of the two-lane highway with passing lanes is constructed or reconstructed—for example, adjacent to a new bridge or where other geometric design improvements are being made—the new segment should be built to new and reconstruction criteria for cross section and clear zones or should at least match the cross section of the existing road segment.

The clear zone width in the passing lane and climbing lane sections should be measured from the outer edge of the through lane as shown in Figure 15.

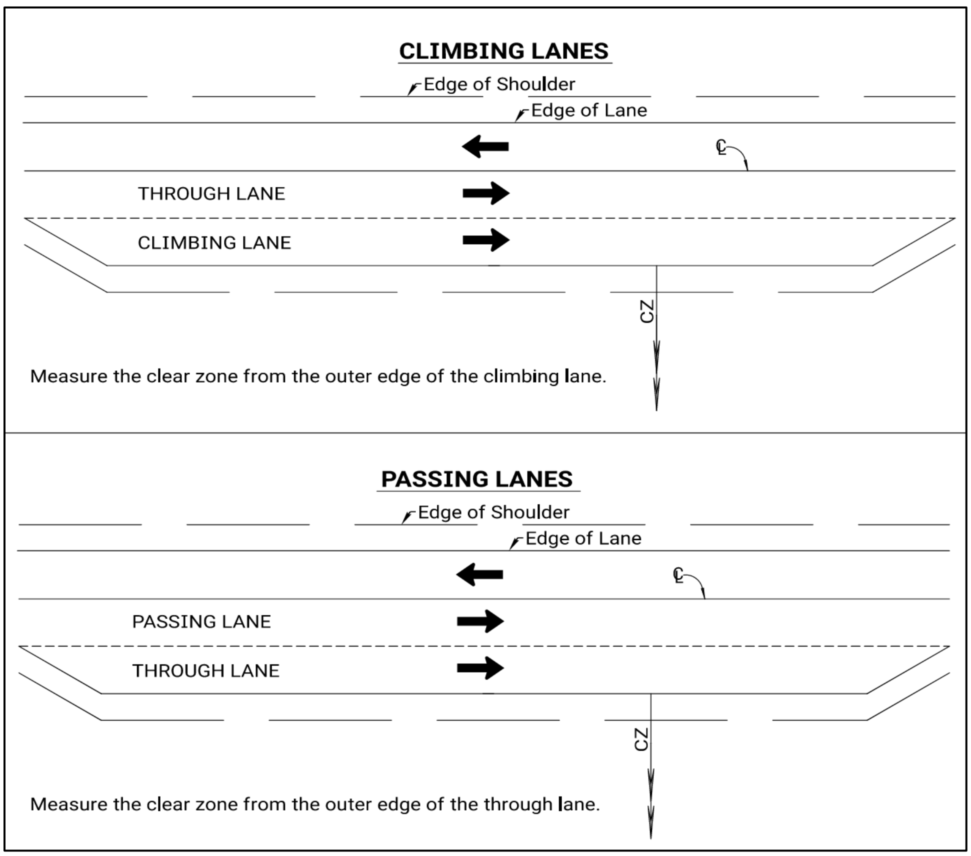

Figure 15: Measuring Clear Zone Width (KDOT, 2025)

6.1.1 Lane Width

The width for all lanes on two-lane highways within passing-lane sections should be 12 ft. Lane widths less than 12 ft may be considered with an appropriate engineering analysis to estimate the roadway performance.

6.1.2 Shoulder Width

The surfaced shoulder width adjacent to passing lanes on two-lane highways should be at least 6 ft, where practical, and may be wider than 6 ft, where appropriate. For example, a wider shoulder may be considered for corridors with higher ADTs, for corridors with substantial motor vehicle, pedestrian, and/or bicycle volumes. Also, the surfaced shoulder width may be designed to match the adjacent sections of two-lane highway. Where constraints are present, shoulders less than 6 ft in width may be considered. Shoulders may be omitted next to passing lanes in curb-and-gutter sections.

Table 7 presents a crash modification factor (CMF) from the HSM that can be used to assess the effect of alternative shoulder widths on specific target crash types identified in the table. The base condition for crash type is 6 ft. CMF values in the table are interpreted as follows. A CMF value greater than 1.00 indicates that the shoulder would be expected to experience more crashes than the base condition. A CMF value less than 1.00 indicates that the shoulder would be expected to experience fewer crashes than the base condition. The CMF value represents the relative frequency of expected crashes in comparison to the base condition.

Table 7: Crash Modification Factor for Shoulder Width on Roadway Segments of Rural Two-Lane Highways (AASHTO, 2010)

Shoulder Width (ft)	Crash Modification Factor (CMF)
0	1.50
2	1.30
4	1.15
6	1.00
8 or more	0.87

NOTE: This table is based on HSM Table 10-9. The target crash types related to shoulder width to which this CMF applies include single-vehicle run-off-the-road and multiple-vehicle head-on, opposite direction sideswipe, and same-direction sideswipe crashes.

6.2 Passing Lane Length

The minimum length to be considered for a passing lane is 0.5 mi. Table 5 indicates that longer passing lanes are desirable as traffic volumes increase. KDOT suggests that passing lanes as short as 0.5 mi only be considered on roadways with lower speeds, lower volumes, or in constrained locations.

The recommended maximum passing lane length is 2.0 mi, including tapers. Longer passing lanes are undesirable operationally because very few passing maneuvers are likely to take place in the furthest downstream portion of longer passing lanes. Where a 2.0 mi passing lane is not sufficient to achieve the target LOS, it is generally more effective operationally to limit the passing lane length to 2.0 mi and then provide another passing lane a few miles down the road. Traffic platooning will likely have risen between the two passing lanes so that the first portion of the downstream passing lane will be more fully utilized for passing than the final portion of the upstream passing lane. However, passing lanes longer than 2.0 mi may be considered where constraints make the provision of a passing lane at another location undesirable or infeasible.

6.3 Lane Addition Transition Area

The lane addition transition area at the beginning of a passing lane should be designed to encourage safe and efficient traffic operations. There is no 2018 *Green Book* (AASHTO, 2018) or 2009 MUTCD (FHWA, 2009) guidance for the length of the lane addition taper at the upstream end of a passing lane. KDOT guidance is that the lane addition taper should be two-thirds of the applicable lane reduction taper length (see Section 7.16 Passing Lanes, KDOT [2014] Bureau of Road Design manual).

For effective passing lane operations, adequate sight distance should be provided 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 may be ineffective.

6.4 Lane Reduction Transition Area

The lane reduction transition taper for a passing lane should be designed to meet MUTCD criteria for taper length (FHWA, 2009), computed as:

$$L = W \times S$$ **Equation 1**

Where:

L = lane reduction taper length (ft)

W = width of lane being dropped (ft)

S = design speed (mph)

In most cases, the outside lane will be dropped at a lane reduction transition, and traffic will move to the inside lane, but in specific cases where it is found to be appropriate, the inside lane may be dropped, and traffic will move to the outside lane.

The lane reduction transition should be located in an area with adequate passing sight distance and above-minimum stopping sight distance.

At the lane reduction taper, the designer may consider geometrics that provide a wider surfaced shoulder. The wider surfaced shoulder would provide a recovery area should drivers encounter a merge conflict at the lane transition area. For additional guidance on lane transitions near intersections, see the Appendix.

6.5 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. Where the presence of higher-volume intersections or driveways cannot be avoided, special provisions for turning vehicles, such as provision of auxiliary turn lanes (e.g., exclusive left- or right-turn lanes), should be considered. Low-volume intersections and driveways do not usually create problems within passing lanes; however, it is desirable to avoid locating the lane-addition and lane-reduction transitions near intersections or driveways, since turning movements are not desirable where drivers may be focused on changing lanes.

6.6 Additional Improvements That May be Considered as Part of Passing Lane Projects

Passing-lane projects may provide an opportunity to consider other improvements within the project limits. Implementing such improvements is not a requirement, but the proposed project may provide a lower-cost opportunity to make such improvements than a later stand-alone project.

6.6.1 Indications of the Need for Improvement at Locations Between Passing Lanes

The conventional two-lane highway between passing lanes should generally be designed in accordance with the applicable geometric design criteria in the KDOT (2014) Bureau of Road Design manual for new or reconstruction projects and the *Policy for Non-Freeway Resurfacing, Restoration and Rehabilitation (3R) Projects* (KDOT, 2018) for rehabilitation or 3R projects, depending on the scope of the project. If the existing roadway does not meet these design criteria, improvements could be analyzed and considered. Additional improvements on the normal two-lane roadway between passing lanes could also be considered in situations identified with the following performance-based criteria for locations where passinglane installation is not planned:

- Traffic operational analysis results indicate that a spot location on the roadway, such as an intersection or driveway, constitutes a bottleneck that is delaying through or turning traffic.
- Review of crash history data shows a concentration or pattern of crashes that is potentially correctable by a geometric design or traffic control improvement
- Forecasts of future crash frequencies indicate an opportunity for a cost-effective geometric design or traffic control improvement to reduce crashes
- Field review or systemic safety analysis of a roadway segment or intersection indicates a potential for future crashes, whether or not there is a recent concentration or pattern of crashes.

Before analysis begins, additional scope items will be reviewed with the KDOT Project Manager for inclusion.

6.6.2 Types of Improvements that May Be Considered

With the approval of the KDOT Project Manager, geometric design and traffic control improvements may be considered for roadway, roadside, and intersection locations within the limits of the project. Guidance on whether and where such improvements should be considered is found in the AASHTO *Green Book* (AASHTO, 2018), the MUTCD (FHWA, 2009), the AASHTO *Roadside Design Guide* (AASHTO, 2011), and in other resources referenced in those documents.

Safety effectiveness measures for many of these improvement types are available in the AASHTO (2010) *Highway Safety Manual*. Typical improvement types that may be considered for such locations are identified below:

- Widen or pave shoulders
- Realign horizontal curves
- Restore superelevation on horizontal curves
- Restore cross slope in normal crown sections
- Install shoulder or centerline rumble strips
- Apply access management principles
- Provide auxiliary lanes at major driveways or intersections
- Review auxiliary lane lengths
- Offset existing auxiliary lanes
- Install or improve lighting
- Provide advance signing for horizontal curves or other features
- Restore or improve pavement markings
- Flatten sideslopes
- Remove or relocate roadside objects to increase clear roadside recovery distance
- Install or modernize traffic barriers
- Realign intersection approaches to reduce intersection skew angle
- Provide advance signing for intersections
- Provide transverse rumble strips on STOP-controlled intersection approaches where needed
- Provide alternative intersection design

Any additional improvements should be reviewed with the appropriate KDOT Project or Program Managers and District staff for inclusion or overlap with other planned projects, programs or maintenance activities and to identify appropriate funding sources.

7. PASSING LANE SIGNING AND PAVEMENT MARKINGS

The signing and pavement markings for passing lanes are partially addressed in the MUTCD. The following guidelines are to provide a consistent typical concept for passing lanes utilizing MUTCD (10th edition) criteria and KDOT practices.

7.1 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 transition
- In advance of the lane-reduction transition
- In the opposing lane

There is no required signing in advance of a passing lane. However, it is desirable to inform drivers that there is a passing lane ahead, so they can anticipate a passing opportunity that is not constrained by sight distance or opposing traffic. Figure 16 illustrates a guide sign (KD14-1) that can be used 2 mi in advance of a passing lane to potentially reduce the frustration and impatience of drivers following a slow-moving vehicle. Driver frustration and impatience when following slow-moving vehicles has been shown to be a potential safety concern on two-lane highways.

Figure 16: Typical Signs Used 2 Miles in Advance of Passing Lane (KD14-1 [2 MILES])
Details for Sign KD14-1 available upon request from KDOT.

Signing is also desirable 0.5 mi in advance of each passing lane. Such signs not only serve to encourage drivers to wait for an upcoming passing opportunity, but also help drivers prepare to choose to enter either the right or left lane at the lane-addition transition so they can make effective use of the passing lane. Signing for use 0.5 mi in advance of a passing lane is shown in Figure 17.

Figure 17: Typical Sign Used 0.5 Miles in Advance of a Merging Lane (K17-1 [1/2 MILE])
Details for Sign K17-1 available upon request from KDOT.

The black-on-white regulatory sign with the legend KEEP RIGHT EXCEPT TO PASS (KR4-3a), as illustrated in Figure 18, may 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 drivers to enter the right lane unless they intend to immediately initiate a passing maneuver.

Figure 18: Black-on-White Regulatory Sign with the Legend "Keep Right Except to Pass" (KR4-3a)
Details for Sign KR4-3a available upon request from KDOT.

The MUTCD (FHWA, 2009) states that a LANE ENDS (W4-2) sign (see Figure 19) should be used to warn drivers of a reduction in the number of traffic lanes in their direction of travel. The placement of this sign is addressed below.

Figure 19: Black-on-Yellow Lane Ends Sign (W4-2) (FHWA, 2009)

The NO PASSING ZONE pennant sign (W14-3), shown in Figure 20, should be placed on the left side of the road at the beginning of each no-passing zone, including no-passing zones on the conventional two-lane highway and no-passing zones in the single-lane direction opposite to a passing lane section.

Figure 20: Black-on-Yellow Pennant-Shaped Warning Sign with the Legend "No Passing Zone" (W14-3) (FHWA, 2009)

Figure 21 shows the typical sequence of signing for passing lanes on two-lane highways. Table 8 also provides the sign spacing for the black-on-yellow lane ends sign (W4-2).

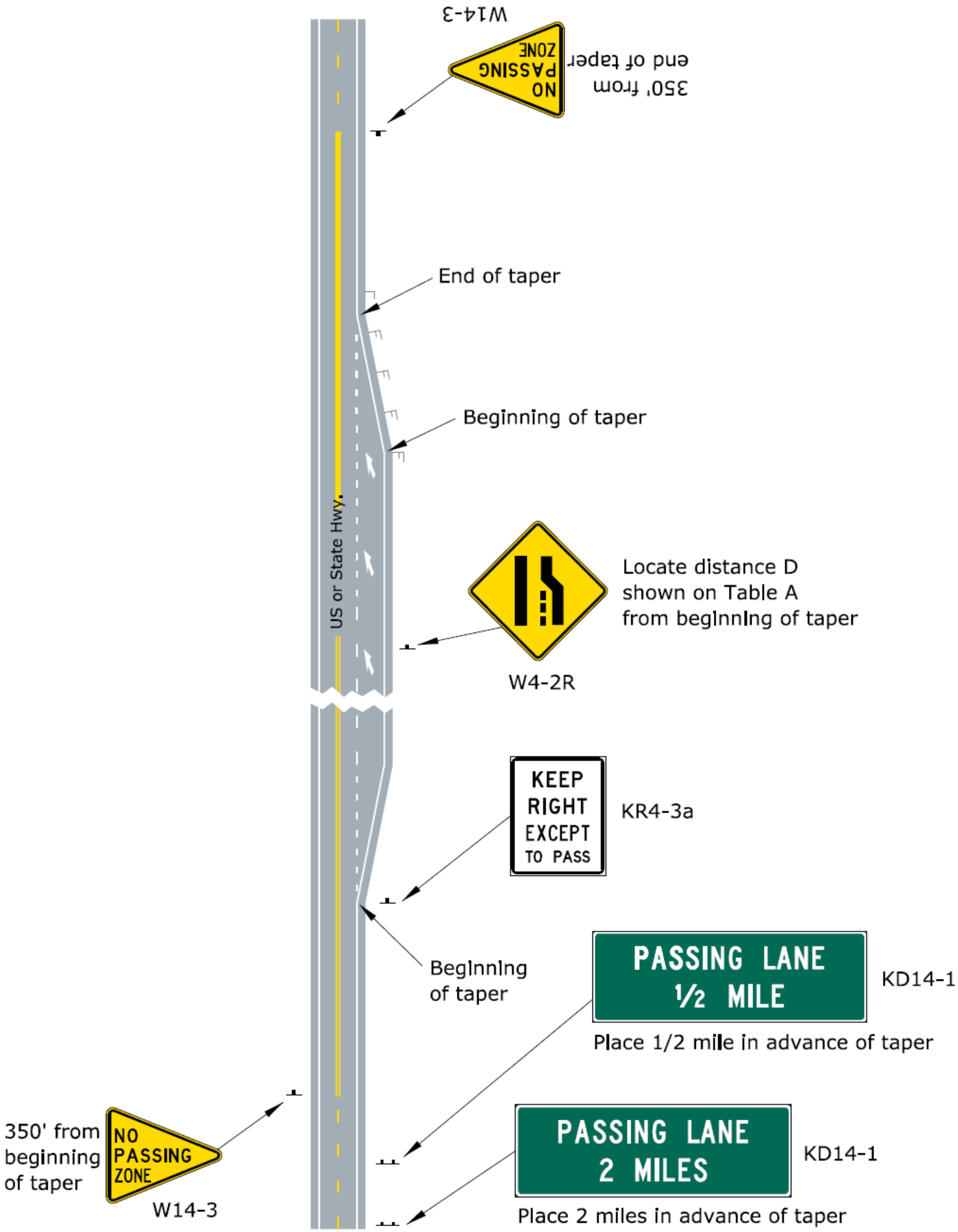

Figure 21: Typical KDOT Signing and Markings for Passing Lanes on Two-Lane Undivided Roadway

Table 8: W4-2 Sign Spacing

Posted Speed (mph)	Conventional Roadway or Urban Lane Reduction (Feet)
20	175
25	250
30	325
35	400
40	475
45	550
50	625
55	700
60	775
65	850
70	N/A

NOTE: This table is based on KDOT typical practices and Engineering Judgement.

7.2 Pavement Marking

KDOT policy is to use a double yellow centerline marking within passing-lane sections and for 350 ft outside the tapers at each end of the passing lane. Figure 22 shows the typical pavement markings for within a passing lane going one direction with the double yellow lines between the single through lane going the opposite direction. A broken white lane line is used to separate traffic in lanes normally moving in the same direction of travel. Pavement edge lines should be used on both sides of the highway in passing lane sections to guide drivers and to delineate the boundary between the pavement and shoulder. No-passing zone markings should be accompanied by appropriate signing (see Section 7.1.4).

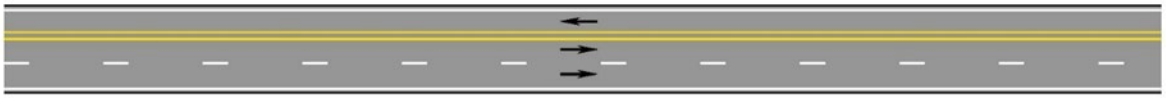

Figure 22: Typical Three-Lane, Two-Way Marking with Passing Prohibited in Single Lane Direction (MUTCD Figure 3B-3) (FHWA, 2009)

The MUTCD (FHWA, 2009) does not provide any specific guidance for marking a lane-addition transition area of a passing lane. KDOT's method of marking a lane-addition transition area is shown in Figure 21. Two alternative methods of marking a lane-addition transition area at the beginning of a passing lane are shown in Figure 23 (see Harwood & Hoban, 1987; St. John & Harwood, 1986). At this time, KDOT is not ready to use the alternatives shown in Figure 23 on projects, and the current method shown in Figure 21 should be utilized. Before consideration of use of an alternative style on a project, the KDOT Bureau of Traffic Engineering would need to be contacted to discuss pavement marking maintenance. These alternatives shown in Figure 23 are discussed further for information only. The taper length for each of the alternatives shown in Figure 23 should be based on a taper rate of 1:50. Passing lanes work most effectively where most drivers choose to enter the right lane at the lane addition and a few drivers who desire to pass immediately enter the left lane. The alternatives shown in Figure 23 provide positive guidance so that most drivers will decide to enter the right lane within the passing lane section.

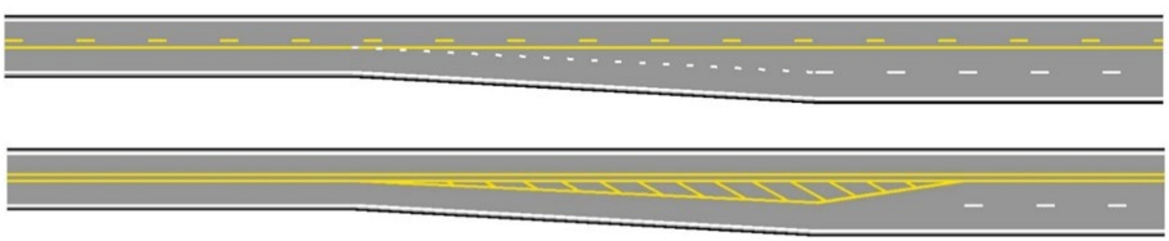

Figure 23: Alternative Marking Applications for Lane-Addition Transition at the Beginning of a Passing Lane Section (Harwood & Hoban, 1987; St. John & Harwood, 1986)

Pavement markings in the lane-reduction transition area should be provided in accordance with MUTCD Section 3B.09 (FHWA, 2009), as illustrated in Figures 24 and 25. The use of a pavement edge marking in the lane-reduction transition area is recommended. Taper rates should be in accordance with the MUTCD (FHWA, 2009).

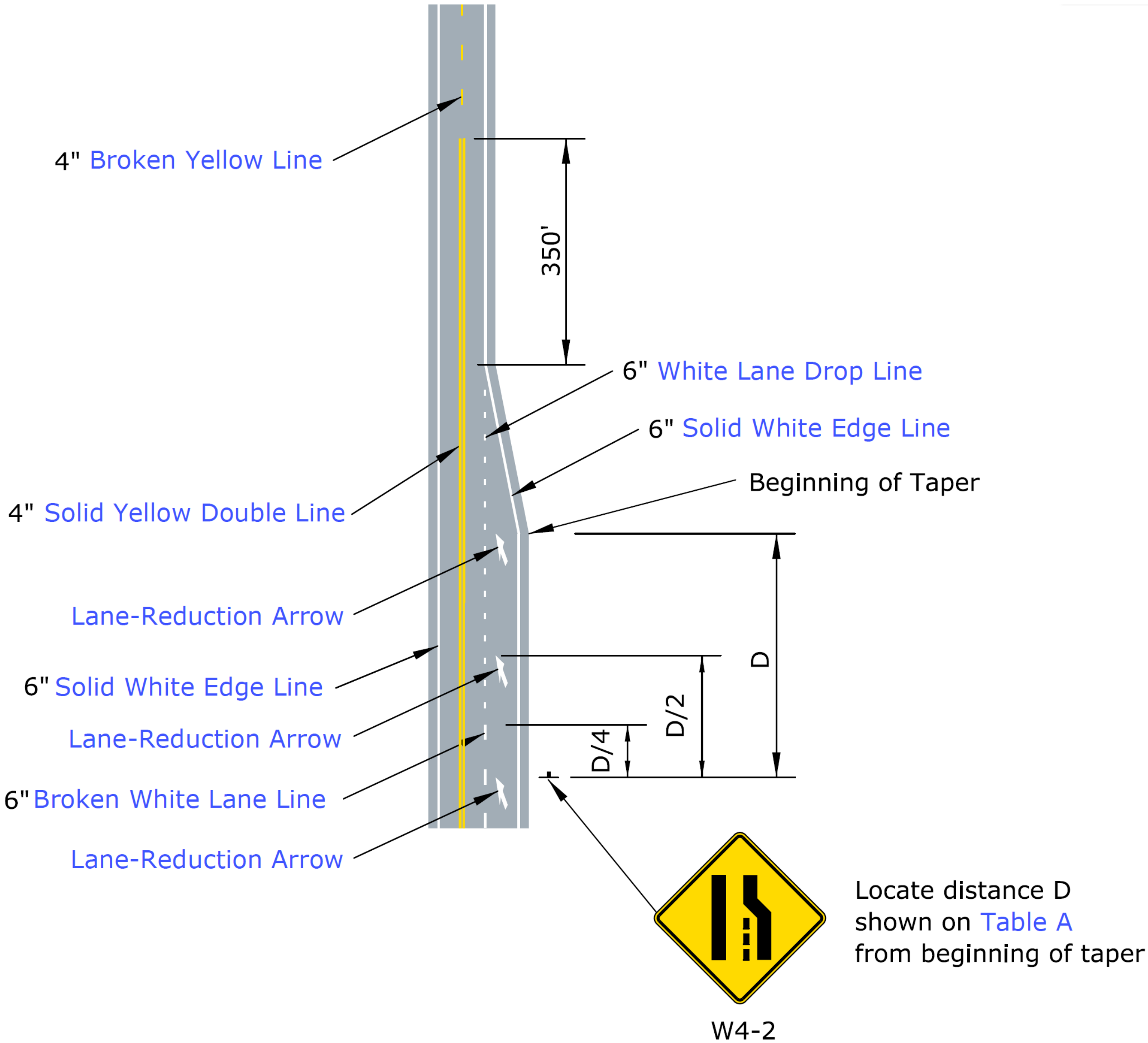

Figure 24: Typical Lane-Reduction Transition Markings (FHWA, 2009)

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Appendix: Pavement Marking and Signing for Lane-Reduction Transitions Near Intersections

High-volume intersections and intersections in the lane-addition and lane-reduction transition areas are discouraged within passing lanes. In general, it is recommended that intersections be located near the middle of a passing lane, rather than near the ends. If an intersection is located near the lane-reduction transition, the further away the intersection is from the lane-reduction transition the better. Layouts for signing and pavement marking for intersections near the lane-reduction transition are described below. The guidance in this appendix represents current KDOT practices for signing and roadway marking of lane-reduction transitions near intersections but is not an official policy.

KDOT's typical practice is to install the warning sign for a lane-reduction transition (W4-2) 850 ft in advance of the beginning of the lane-reduction transition taper on a conventional highway with a speed limit of 65 mph. The lane-line pavement markings end at a point approximately 212 ft downstream of the W4-2 sign (25 percent of the distance between the W4-2 sign and the beginning of the lane-reduction-transition taper), consistent with MUTCD Section 3B.09 (FHWA, 2009).

The following three lane-reduction-transition scenarios for passing lanes describe three situations in which KDOT's typical signing and marking practice can be applied. These scenarios describe the placement of the signs and markings for a lane-reduction transition near an intersection in relation to the approach radius return point (ARRP) upstream of the intersection and the departure radius return point (DRRP) downstream of the intersection. For questions regarding other situations please contact the KDOT Bureau of Traffic Engineering, Signing Section.

A.1 Scenario 1—Lane-reduction-transition taper begins at least 950 ft downstream of the DRRP at the intersection

Where the beginning of the lane-reduction transition taper is at least 950 ft downstream from the DRRP at the intersection, KDOT's practice is to install the W4-2 sign at least 100 ft downstream from the DRRP. The lane-line pavement markings would end, and the lane-drop-line pavement markings would begin, at a point approximately 212 ft downstream from the W4-2 sign. Three lane-reduction-transition arrow pavement markings are used. In this scenario, both lanes within the passing-lane section are full width through the intersection. Figure A.1 illustrates the placement of signs and markings for this scenario.

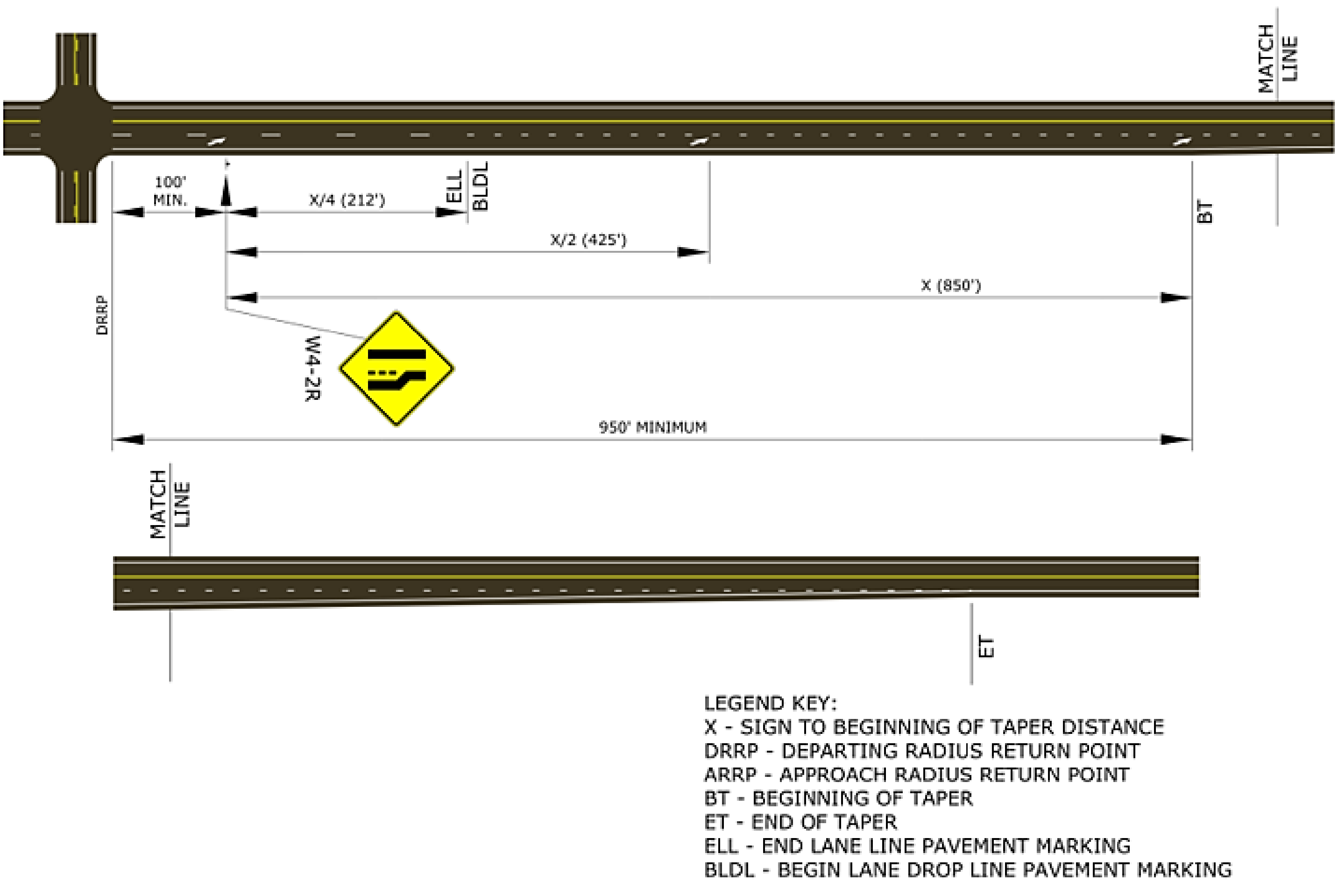

Figure A.1: Placement of Lane-Reduction Signing and Marking for Scenario 1

A.2 Scenario 2—Lane-reduction-transition taper begins at least 750 ft downstream of the ARRP at the intersection and less than 950 ft downstream of the DRRP at the intersection

Where the beginning of the lane-reduction-transition taper begins at least 750 ft downstream of the ARRP and less than 950 ft downstream from the DRRP at the intersection, KDOT's practice is to install the W4-2 sign 100 ft upstream of the ARRP. This will allow the lane-line pavement markings to end, and the lane-drop-line pavement markings to begin, at a point 638 ft upstream from the beginning of the lane-reduction-transition taper. Three lane-reduction-transition arrow pavement markings are used. In this scenario, both lanes within the passing-lane section are full width through the intersection. Figure A.2 illustrates the placement of signs and markings for this scenario.

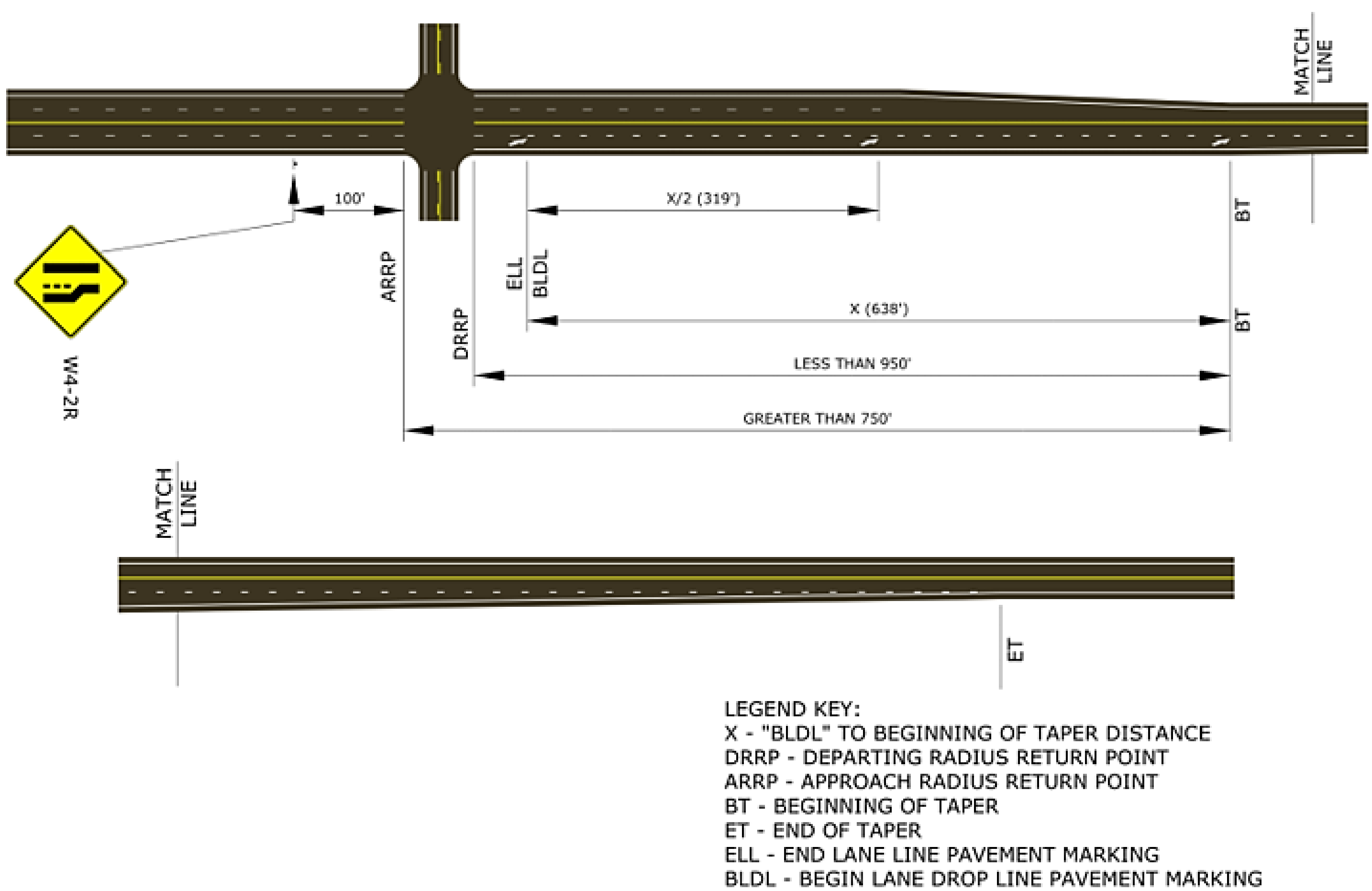

Figure A.2: Placement of Lane-Reduction Signing and Marking for Scenario 2

A.3 Scenario 3—Lane-reduction-transition taper begins 638 to 750 ft downstream of the ARRP at the intersection

Where the beginning of the lane-reduction-transition taper is between 638 and 750 ft downstream from the ARRP at the intersection, KDOT's practice is to install the W4-2 sign 212 ft upstream of the ARRP. This allows the lane-line pavement markings to end at the ARRP of the intersection. The lane-drop-line pavement markings begin at the DRRP. Three lane-reduction-transition arrow pavement markings are used. In this scenario, both lanes within the passing-lane section are full width through the intersection. Figure A.3 illustrates the placement of signs and markings for this scenario.

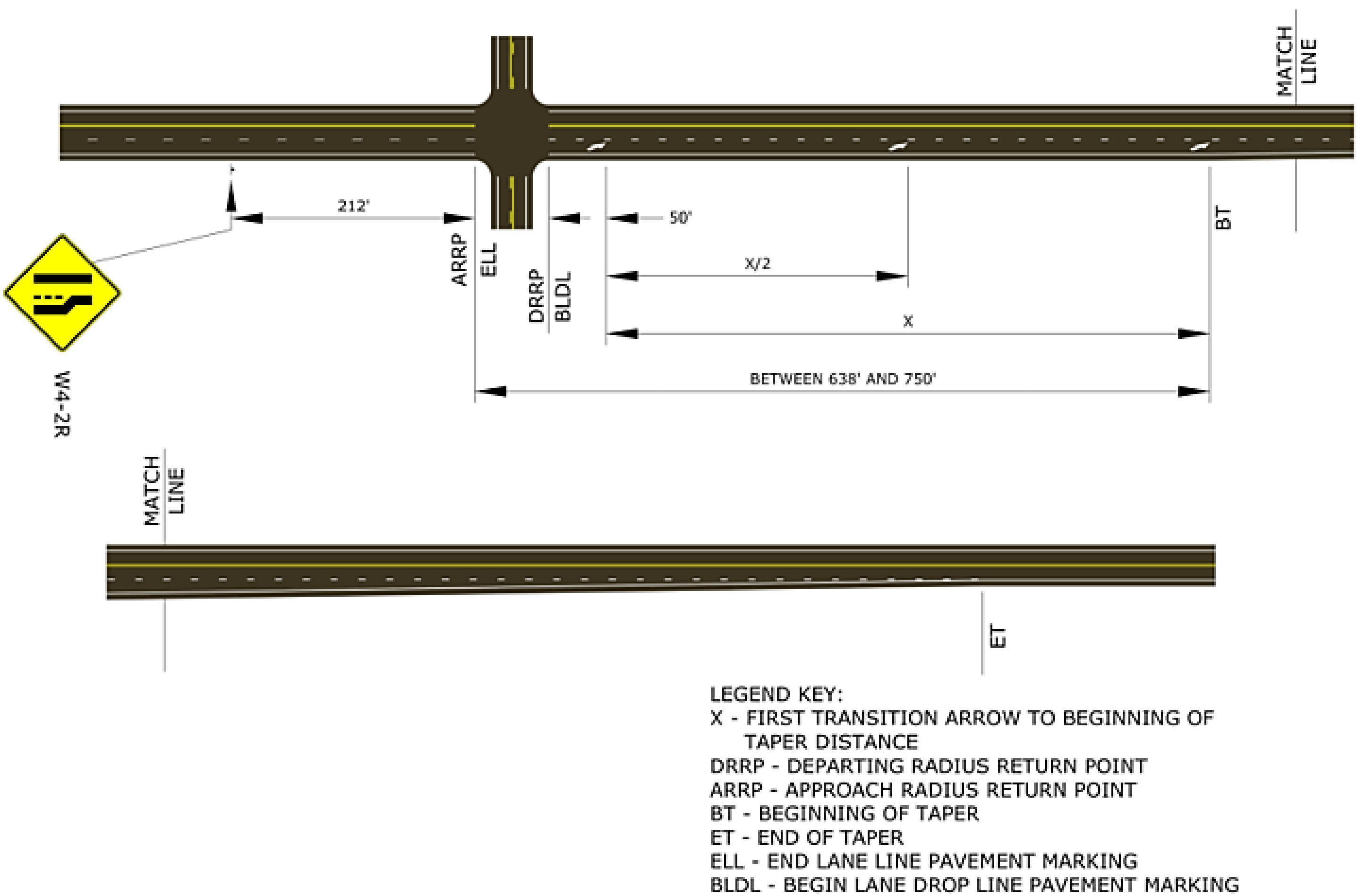

Figure A.3: Placement of Lane-Reduction Signing and Marking for Scenario 3

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